02.08.2018

Digital Image Processing (CSE/ECE 478)

Lecture-2: Digital Imaging Fundamentals

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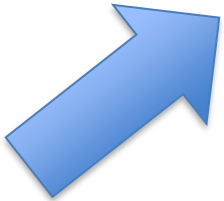
Announcements

- Teaching Assistants
  - Abhishek Prusty (abhishek.prusty@students.iiit.ac.in)
  - Aditya Aggarwal (aditya.aggarwal@students.iiit.ac.in)
  - Prathyakshun Rajashankar (prathyakshun.r@students.iiit.ac.in)
  - Karandeep Singh Juneja (karandeepsingh.juneja@students.iiit.ac.in)
- Tutorial hours: Saturday 3.30p – 4.30p, location: H-203

Announcements

- NO class next Tuesday
- Make-up class: Wednesday, 3.30p - 5.00p, H-103



Elements of Visual Perception

- Designers and often, consumers of Image Processing Techniques, are humans.

- Therefore, it is important to understand the basic workings of the human visual system.

The Human Eye

Diameter: 20 mm

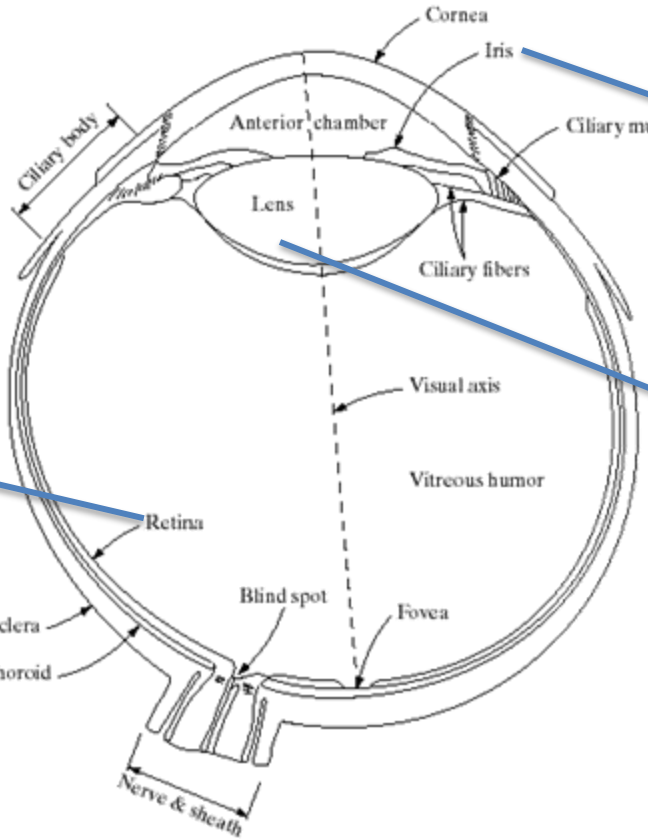
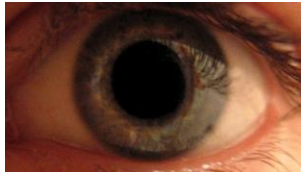


FIGURE 2.1 Simplified diagram of a cross section of the human eye.



2-8mm width,
Contracts / Expands to control amount of light entering the eye

- Absorbs 8% of visible light spectrum
- IR, UV also absorbed

- Light is imaged on this

Reduces backscatter

The Retina

- The retina lines the entire posterior portion.
- Discrete light receptors are distributed over the surface of the retina:
  - cones (6-7 million per eye) and
  - rods (75-150 million per eye)

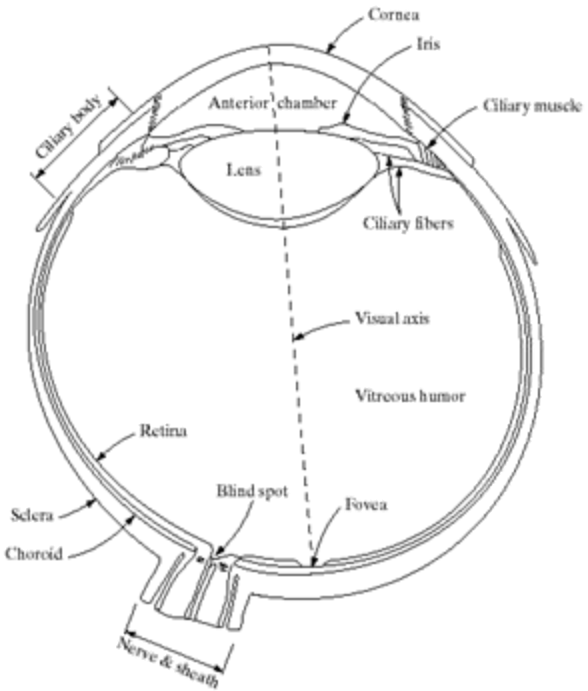
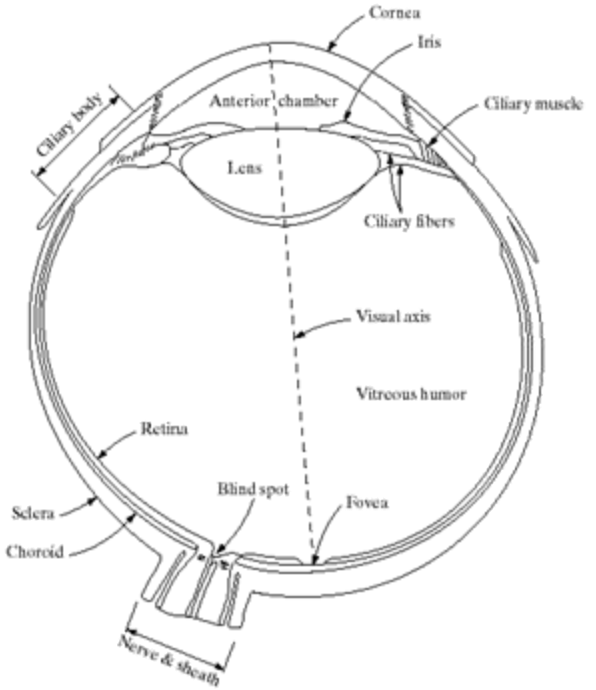


FIGURE 2.1
Simplified diagram of a cross section of the human eye.

Cones

- Cones are located in the fovea and are sensitive to color.
- Each one is connected to its own nerve end.
- Sensitive to bright-light: *photopic* vision



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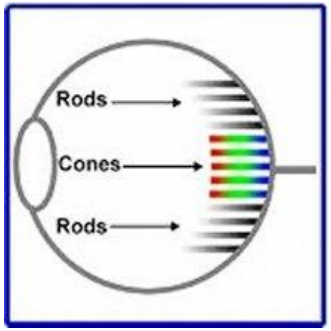
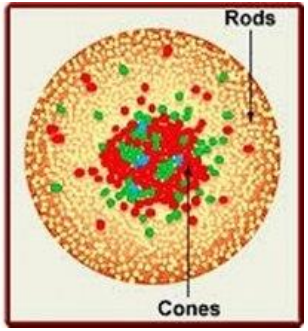
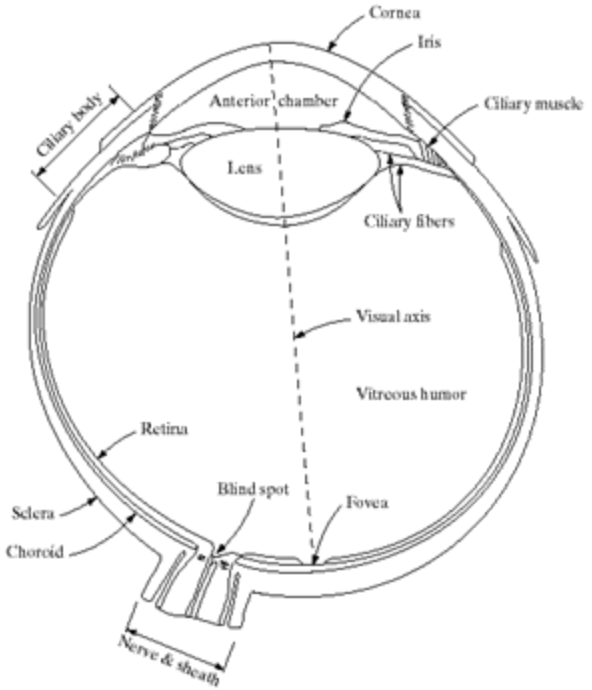




Rods

- Rods give a general, overall picture of the field of view and are not involved in color vision.
- Several rods are connected to a single nerve.
- Rods are sensitive to low levels of illumination (*scotopic* or dim-light vision).



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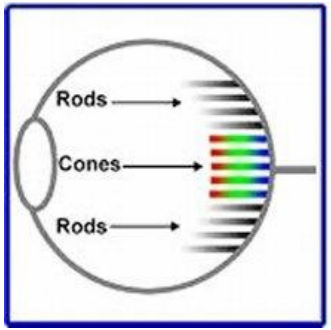
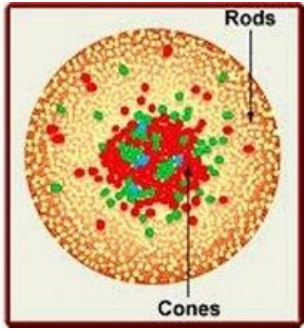




Receptor Distribution

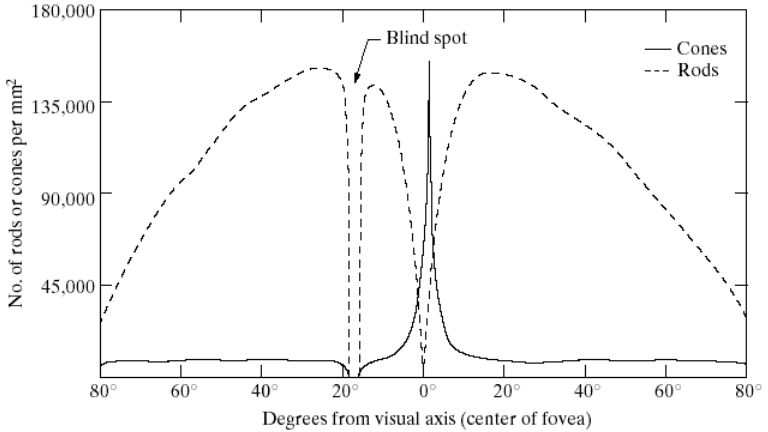


FIGURE 2.2
Distribution of rods and cones in the retina.

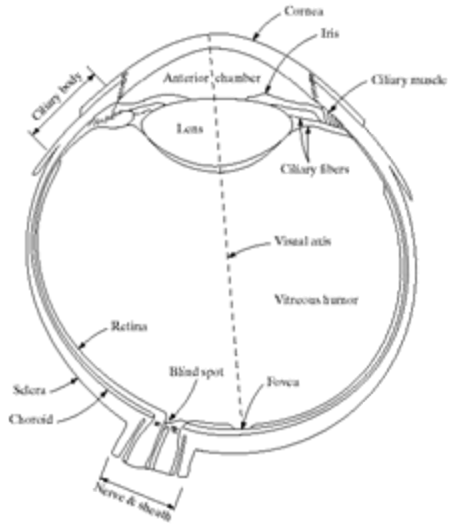


FIGURE 2.1
Simplified diagram of a cross section of the human eye.

- The distribution of receptors is radially symmetric about the fovea.
- Cones are most dense in the center of the fovea
- Rods increase in density from the center out to approximately 20% off axis and then decrease.

The Fovea

- Circular (1.5 mm diameter)
  - can be assumed to be a square sensor array (1.5 mm x 1.5 mm).

- The density of cones: 150,000 elements/mm^2 ~ 337,000 for the fovea.
  - A CCD imaging chip of medium resolution needs 5 mm x 5 mm for this number of elements

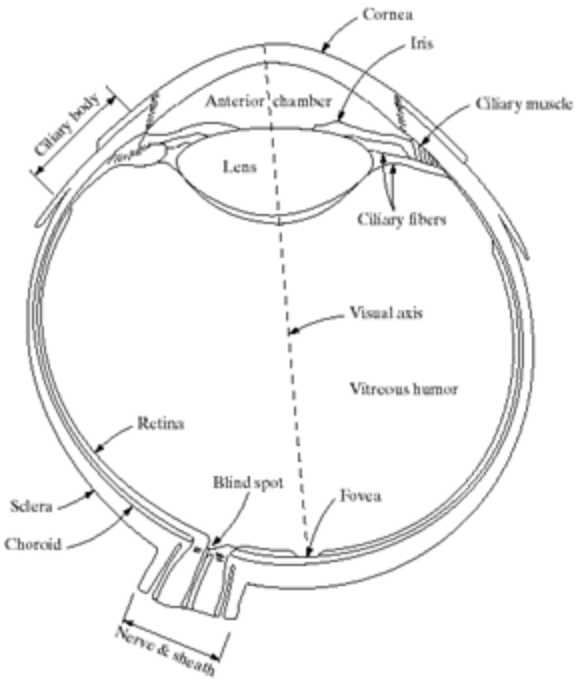


FIGURE 2.1
Simplified diagram of a cross section of the human eye.

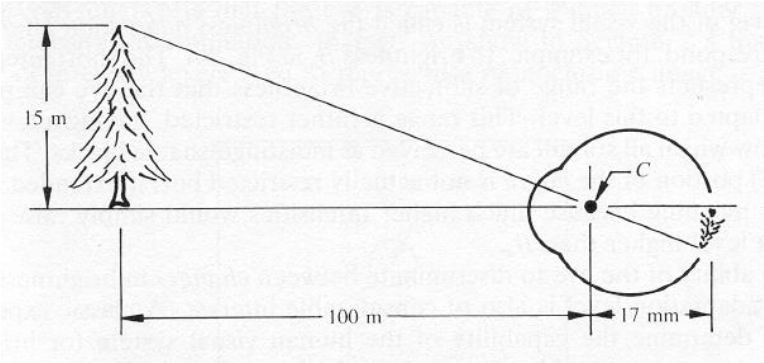
Image Formation in the Eye

- The eye lens (compared to an optical lens) is flexible.

- It gets controlled by fibers of the ciliary body
  - To focus on distant objects it gets flatter (and vice versa)
  - Focal length varies from 17 mm to 14 mm

Image Formation in the Eye

- Example:
  - Calculation of retinal image of an object

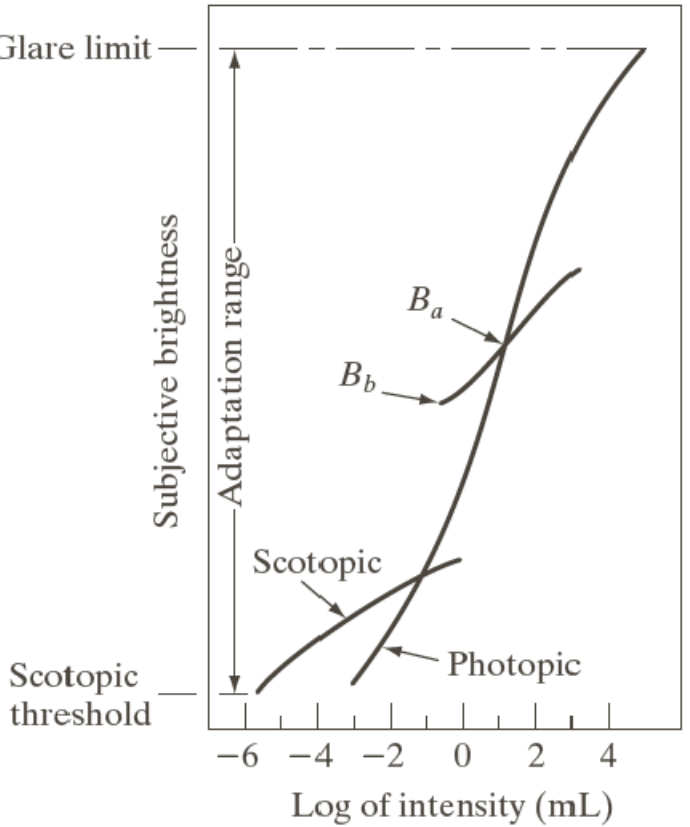


$$\frac{15}{100} = \frac{x}{17}$$

$$x = 2.55mm$$

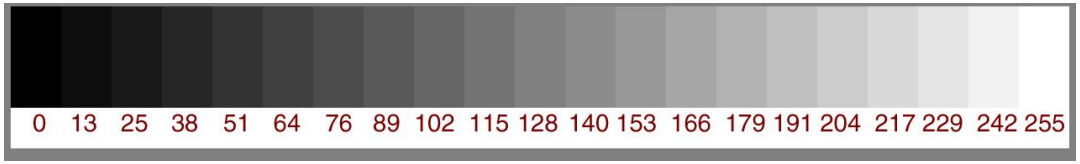
Brightness adaptation

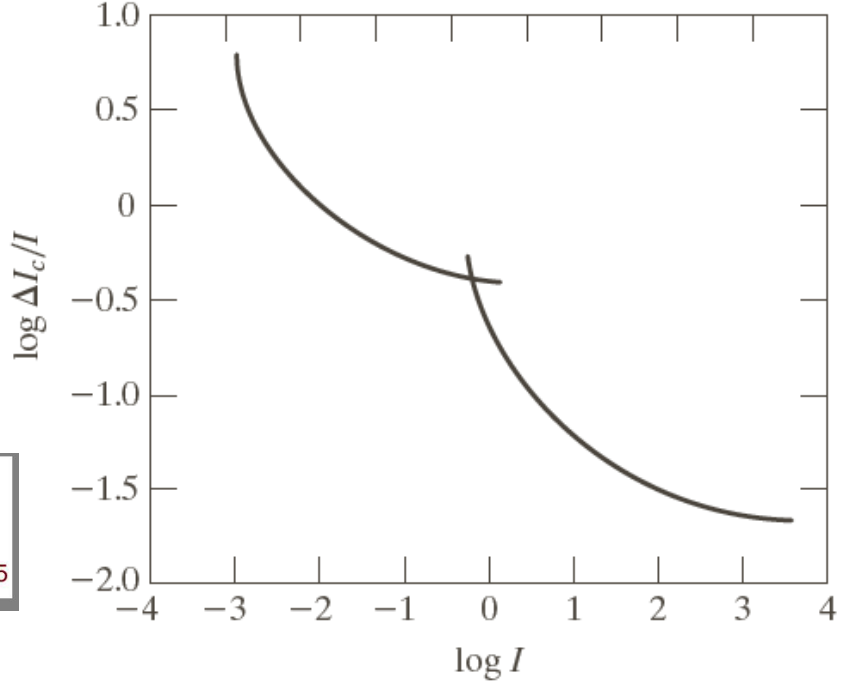
- Dynamic range of human visual system
  - $10^{-6} \sim 10^{4}$
- HVS cannot accomplish this range **simultaneously**
- The current sensitivity level of the visual system is called the **brightness adaptation** level



Brightness discrimination

- Weber ratio (the experiment) $\Delta I_c/I$
  - I: the background illumination
  - ΔI_c : the increment of illumination
  - Small Weber ratio → good discrimination
  - Larger Weber ratio → poor discrimination





https://www.youtube.com/watch?v=hWT_LO8U7uE

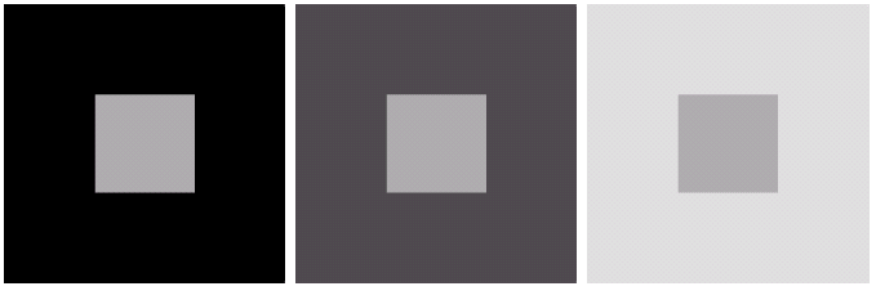
https://www.youtube.com/watch?v=wVhiezByMSU : an audio example

Brightness Adaptation & Discrimination

- Another experiment: Background illumination constant, other source incrementally varies
- The typical observer can discern one to two dozen different intensity changes

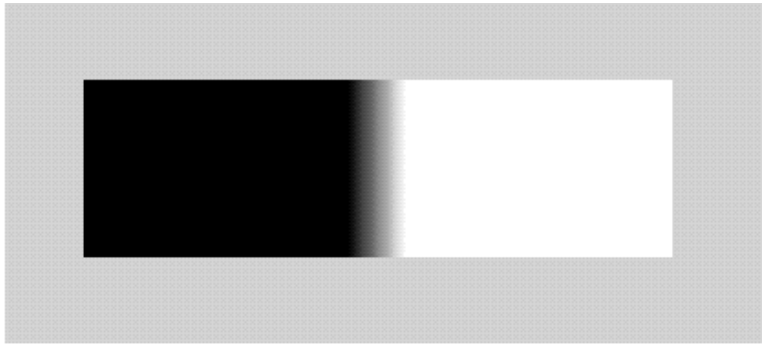
Psychovisual effects

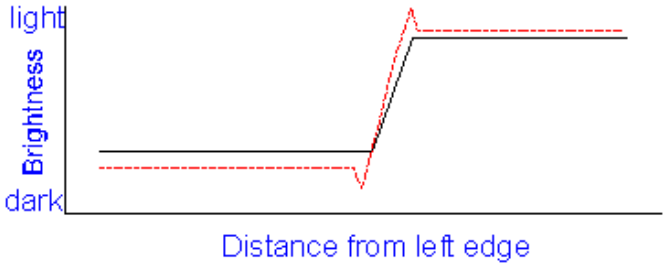
- The perceived brightness is not a simple function of intensity
  - Mach band pattern
  - Simultaneous contrast



a b c

FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.





a b
c d

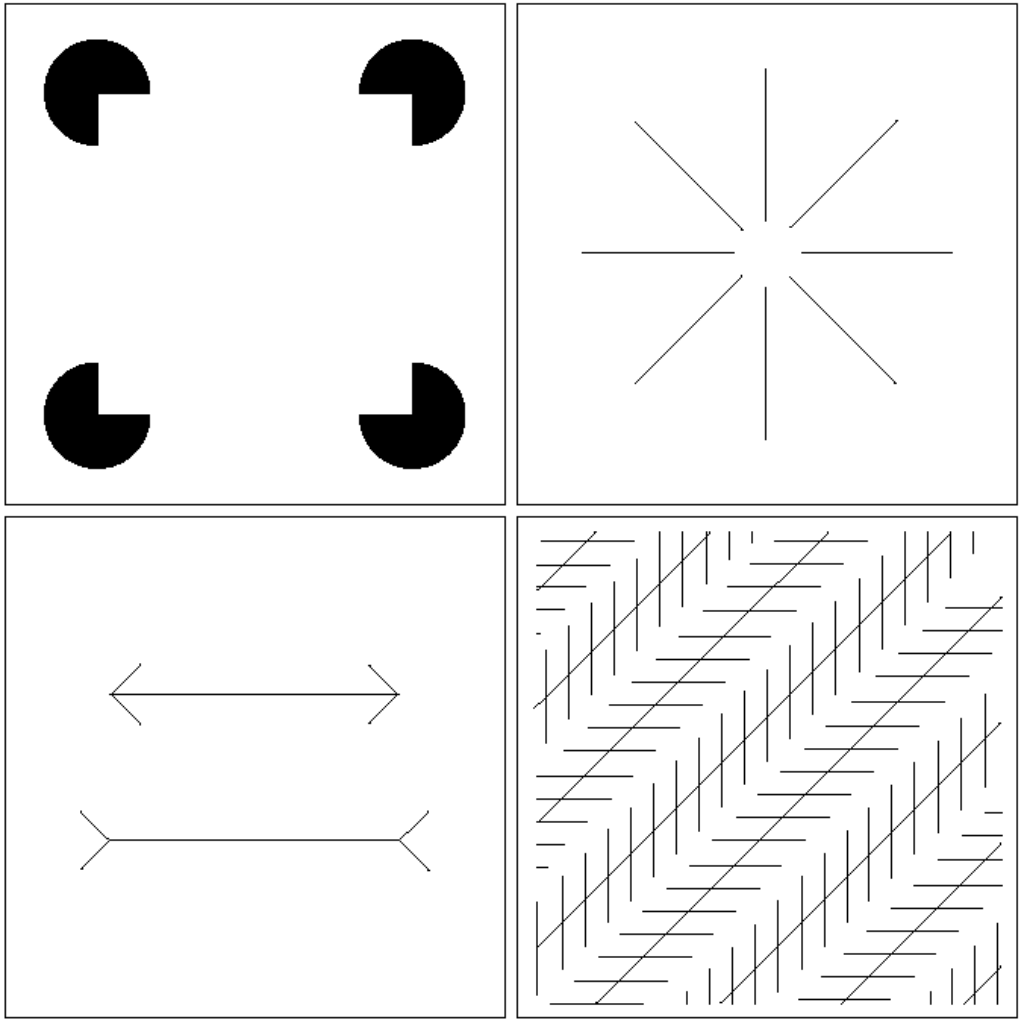
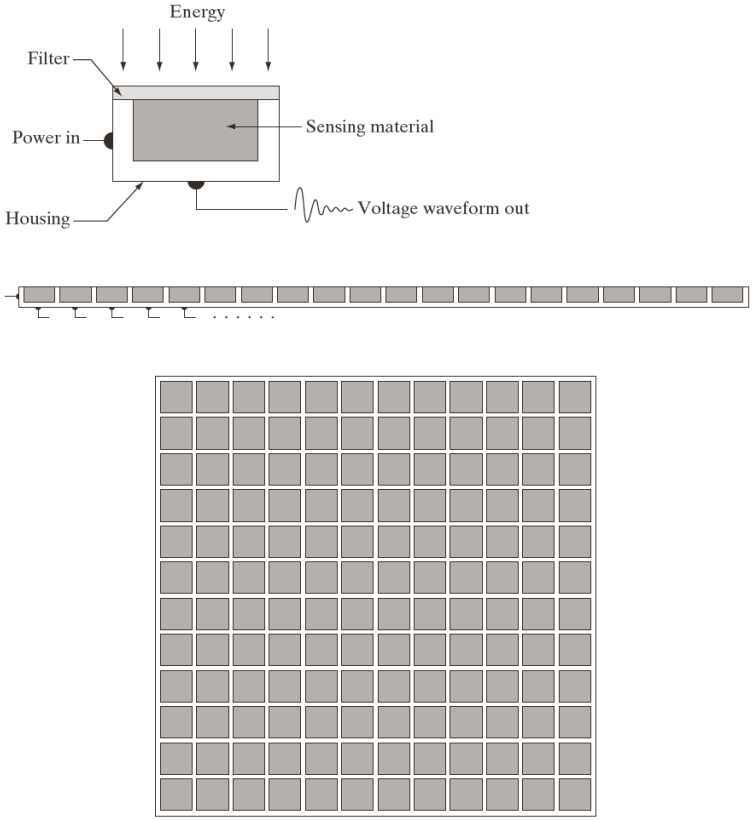


FIGURE 2.9 Some well-known optical illusions.

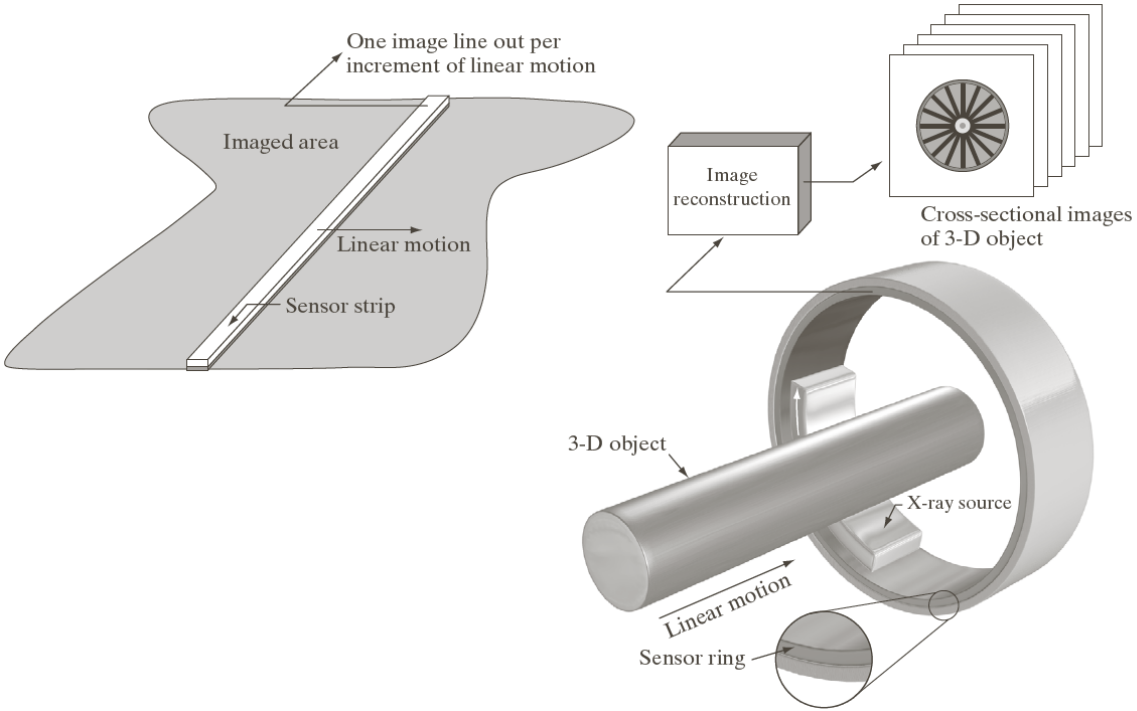
Image Sensing and Acquisition



a
b
c

FIGURE 2.12
(a) Single imaging sensor.
(b) Line sensor.
(c) Array sensor.

Image Sensing and Acquisition



a b

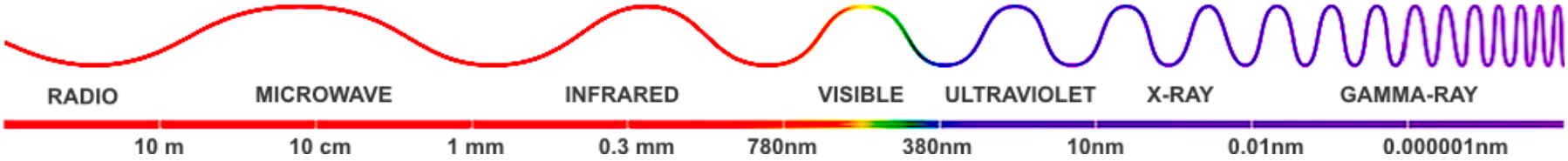
FIGURE 2.14 (a) Image acquisition using a linear sensor strip. (b) Image acquisition using a circular sensor strip.

- **Digital Image Acquisition**
- Image Sampling and Quantization
- Fundamental Steps in Image Processing

How images are acquired

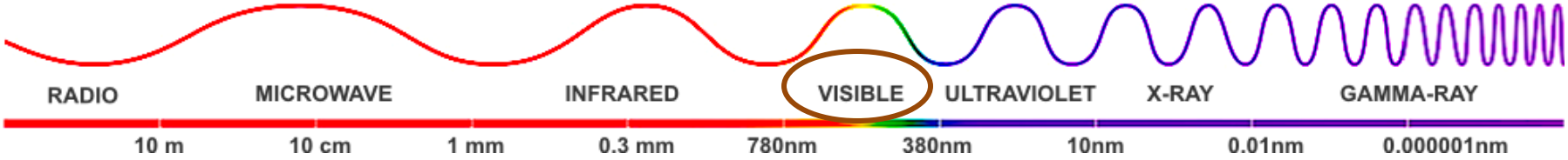
How images end up in digital form

EM spectrum



- EM radiation
  - Energy travelling as a wave
  - Produced by oscillating charge or energy source

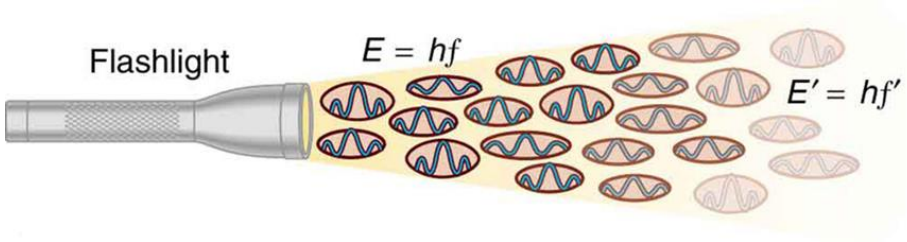
EM spectrum



- EM radiation
  - Energy travelling as a wave
  - Produced by oscillating charge or energy source
- Visible light
  - Band of EM radiation sensed by human eye

Light as a particle stream

- Energy carried by light
  - Not wave-like
  - Discrete (Quantized) particles = Photons



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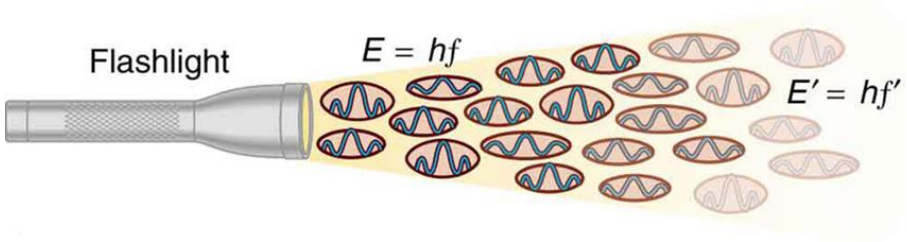


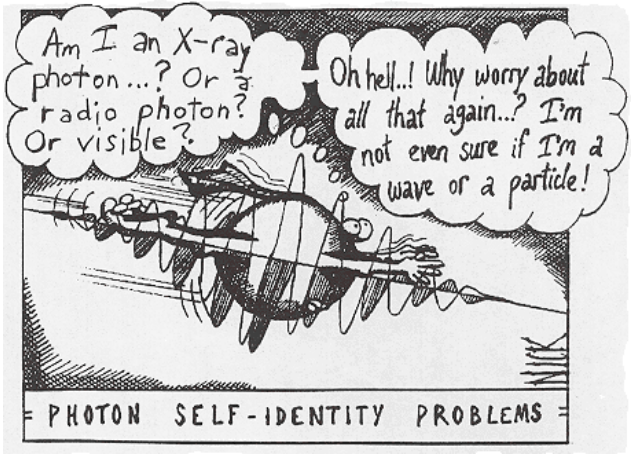
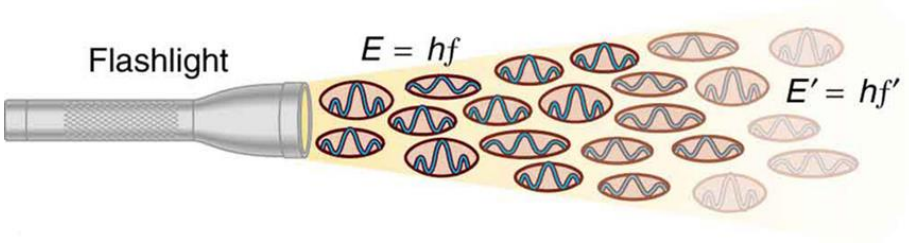
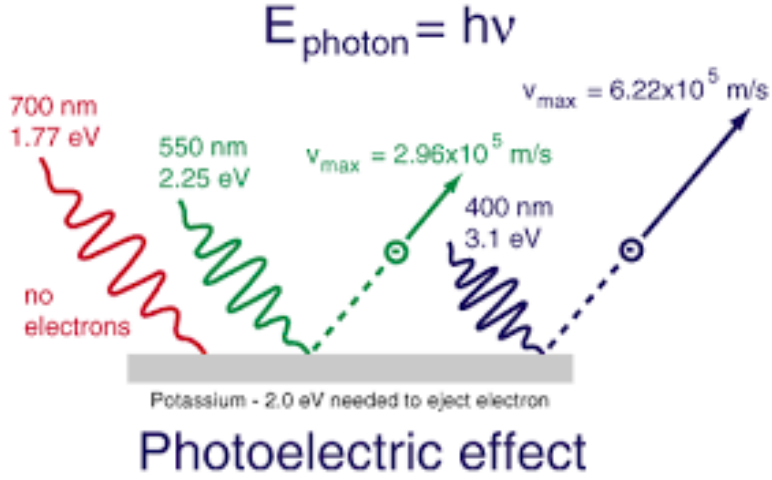


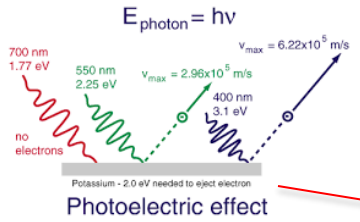
Photo-electric effect

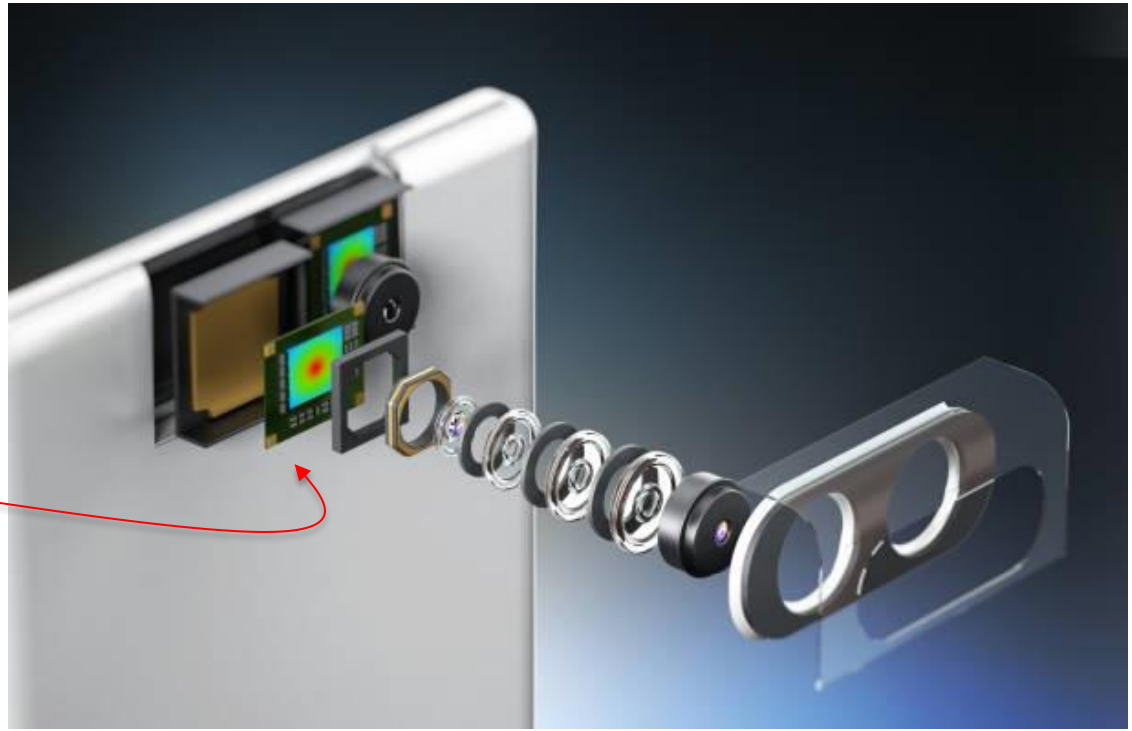




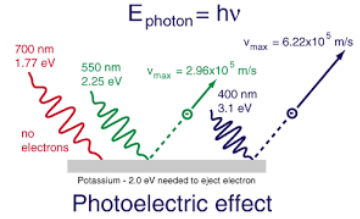
Cross-section of typical smartphone camera

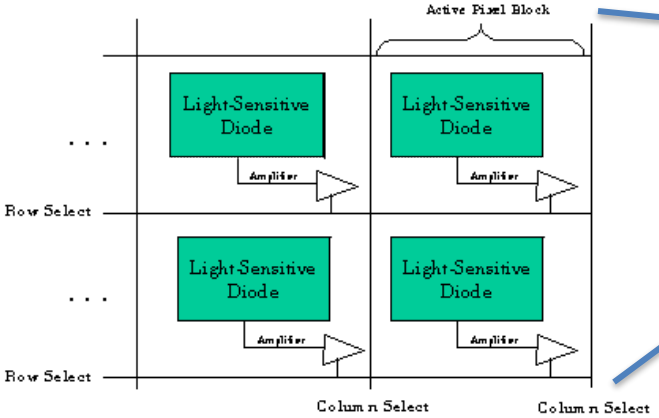
Photo-electric effect in cameras

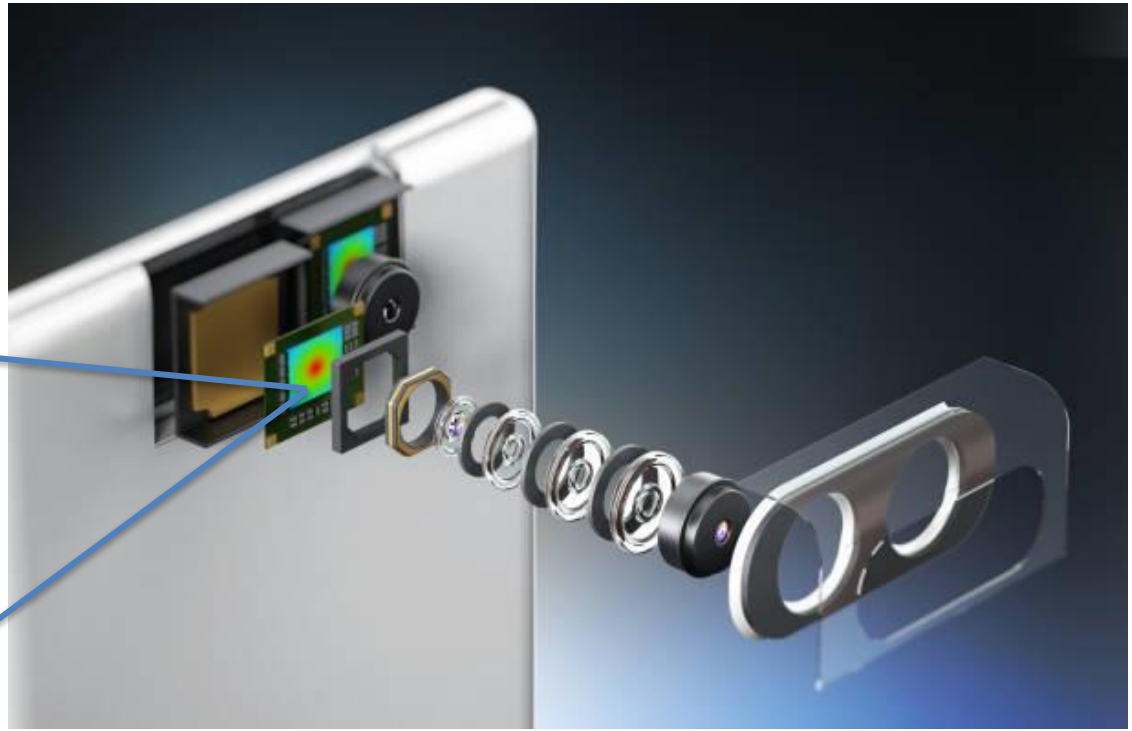




CMOS photo-electric sensor



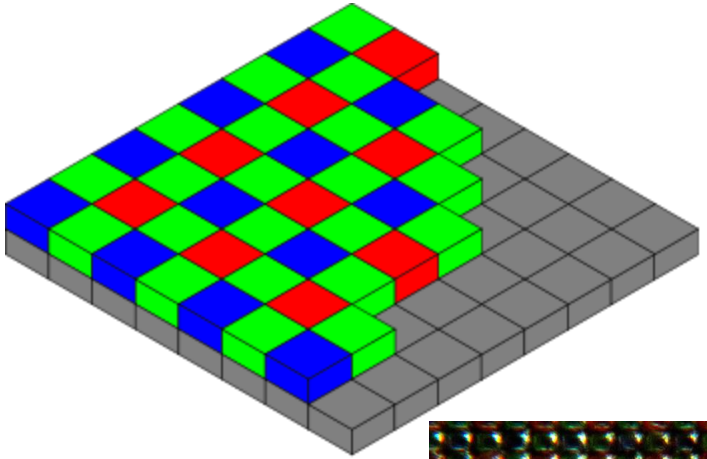


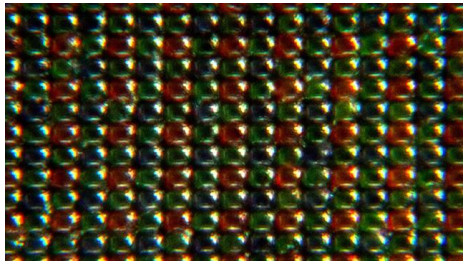


Light → Color

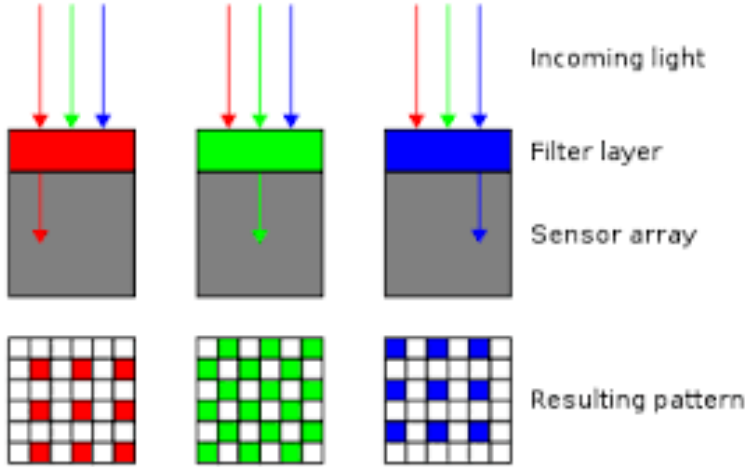
- CMOS sensitive to “light”, not “color”

Bayer Filter





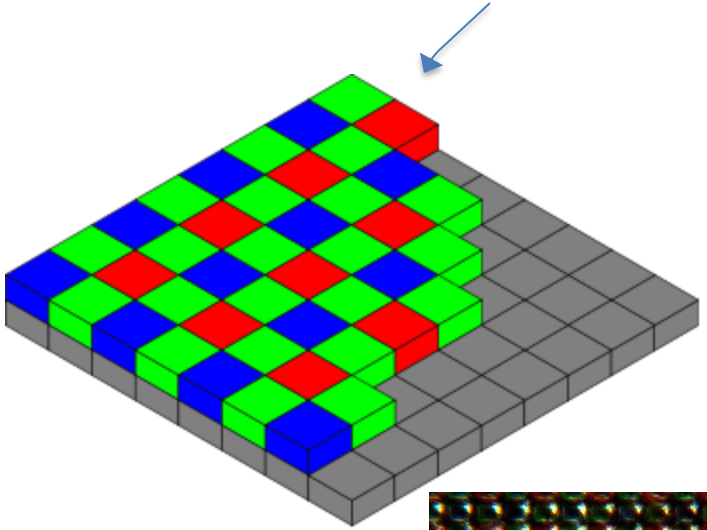
600x

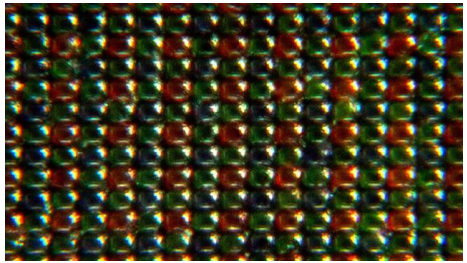


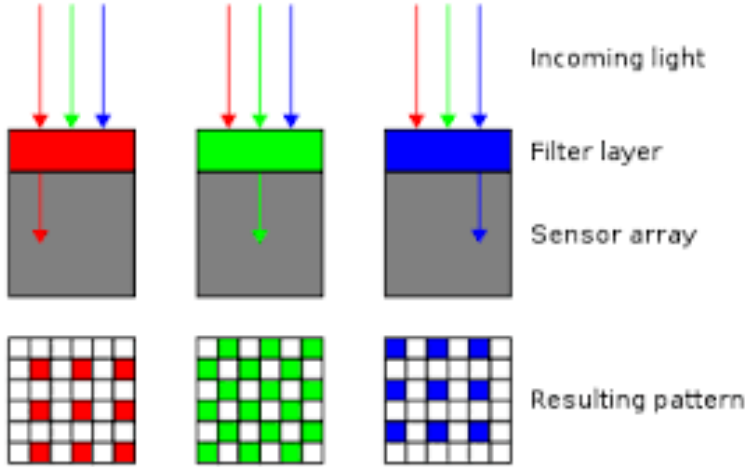
https://en.wikipedia.org/wiki/Bayer_filter

Bayer Filter

Relatively more green filters. Why ?

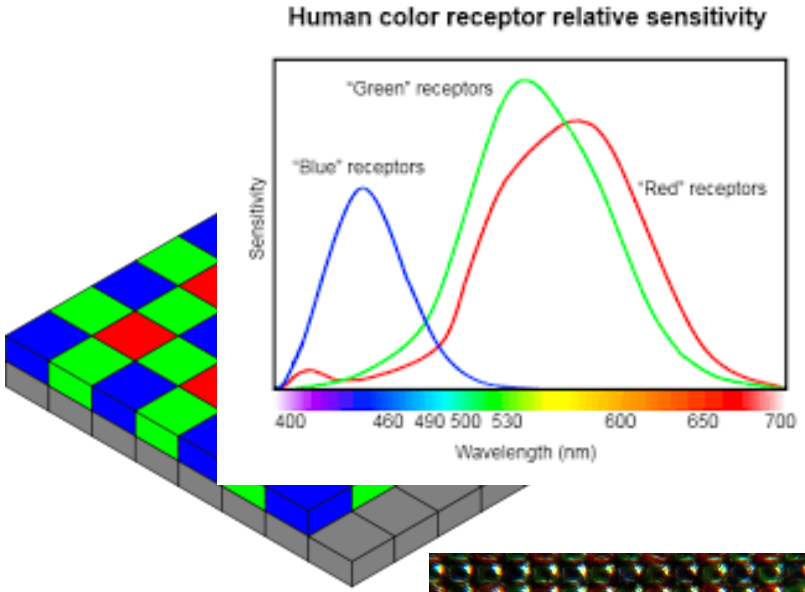


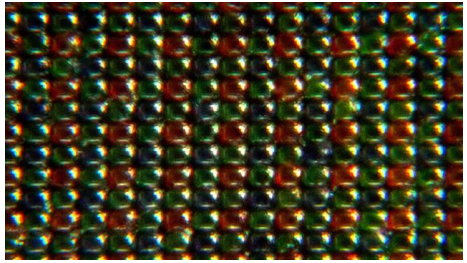




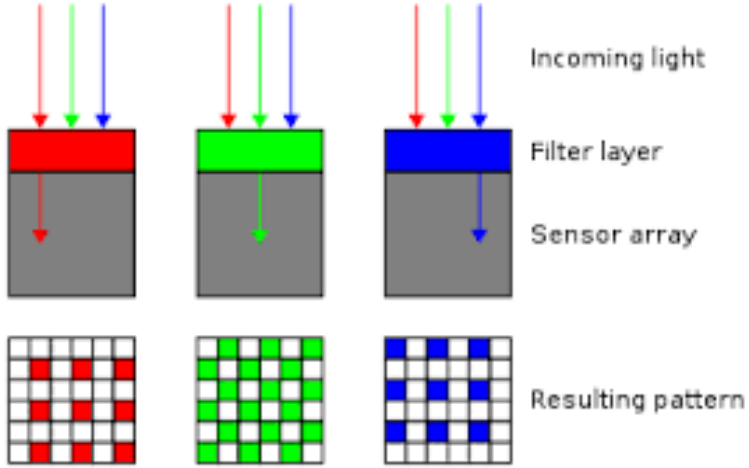
https://en.wikipedia.org/wiki/Bayer_filter

Bayer Filter





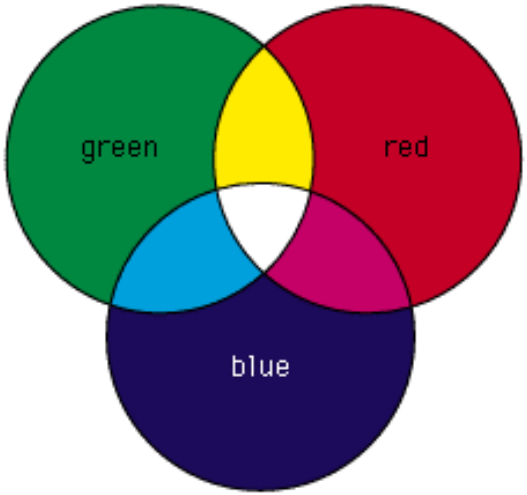
https://petapixel.com/2016/03/30/people-can-see-100-times-colors/

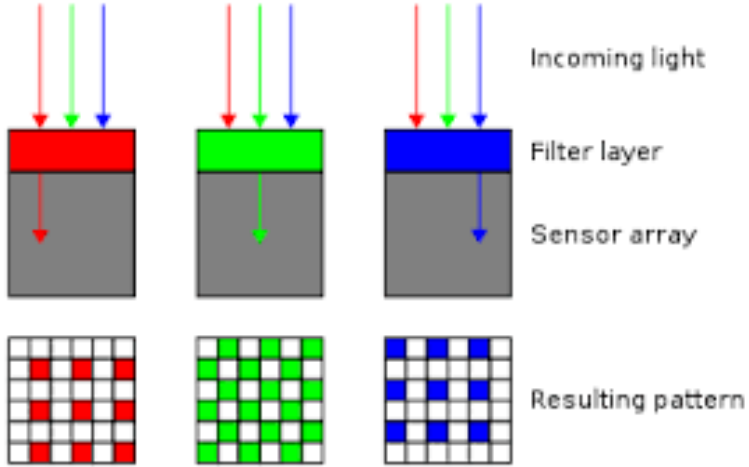


https://en.wikipedia.org/wiki/Bayer_filter

Bayer Filter

- How do we get color now ?





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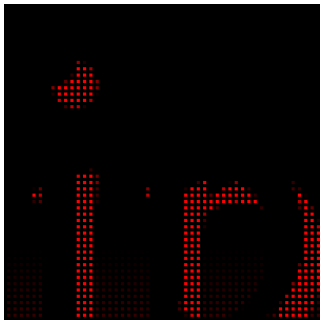
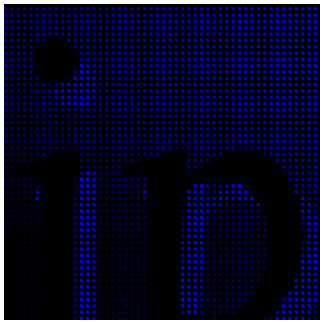
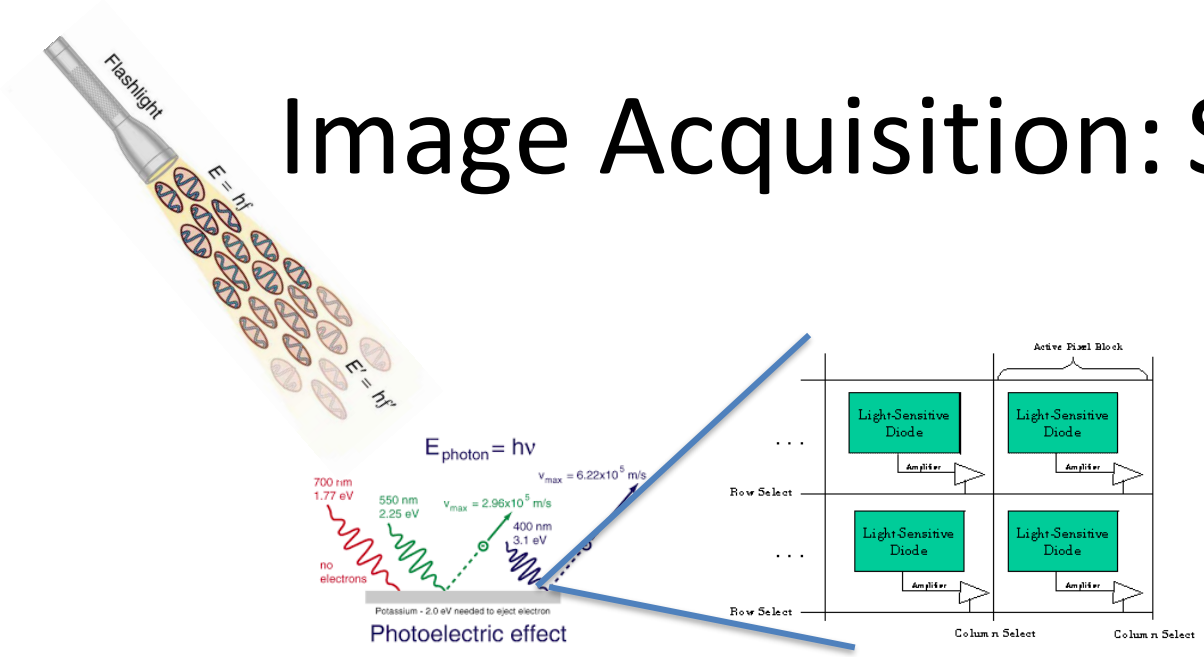
Demosaicing

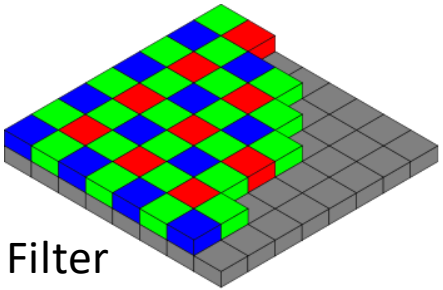




https://en.wikipedia.org/wiki/Demosaicing

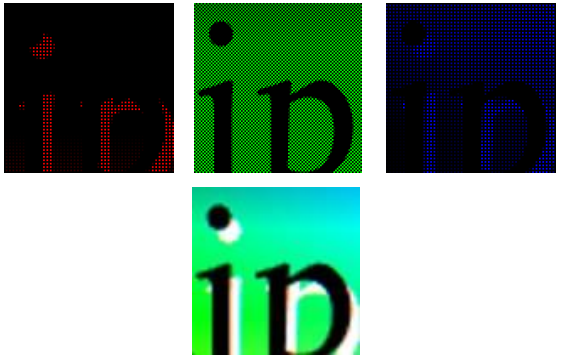
Image Acquisition: Summary





Bayer Filter

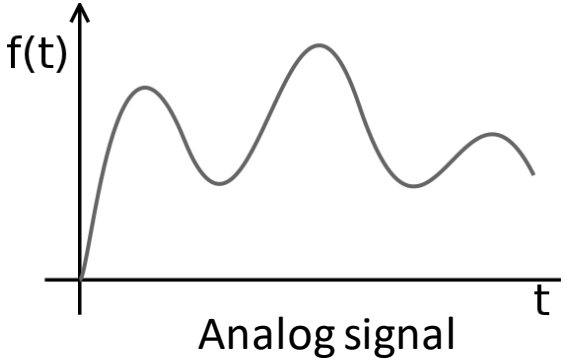
Demosaicing



- Digital Image Acquisition
- **Image Sampling and Quantization**
- Fundamental Steps in Image Processing

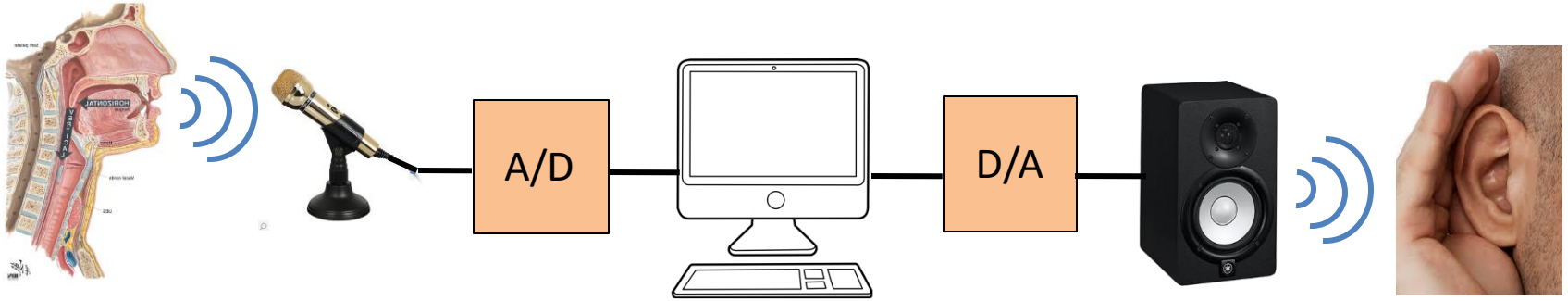
Signal

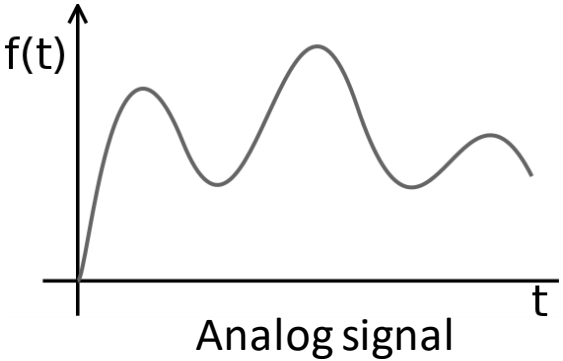
"Function that conveys information about the behavior or attributes of some phenomenon" (wikipedia)



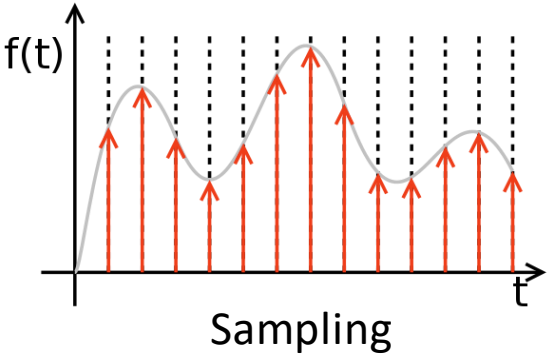
Analog signal

Analog vs. Digital signal (1-D)

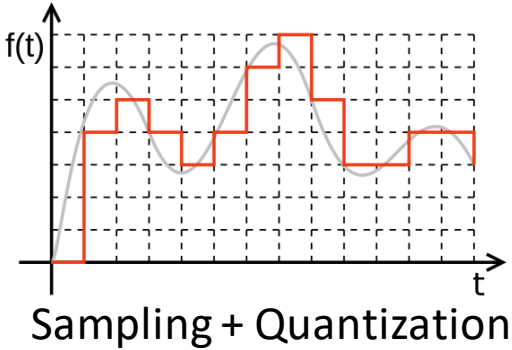




Analog signal



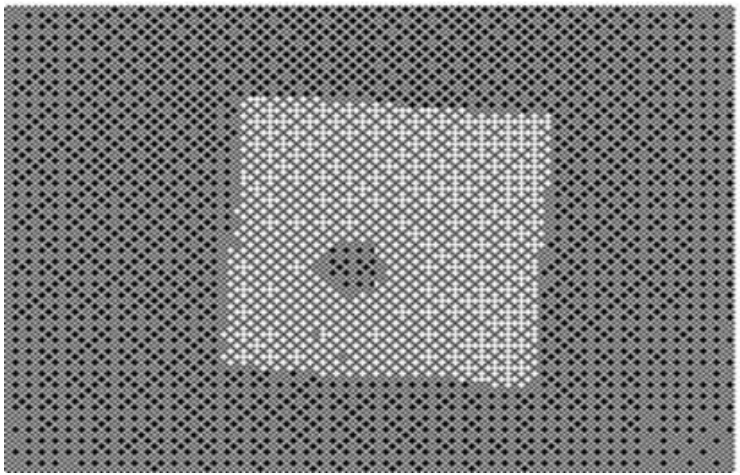
Sampling

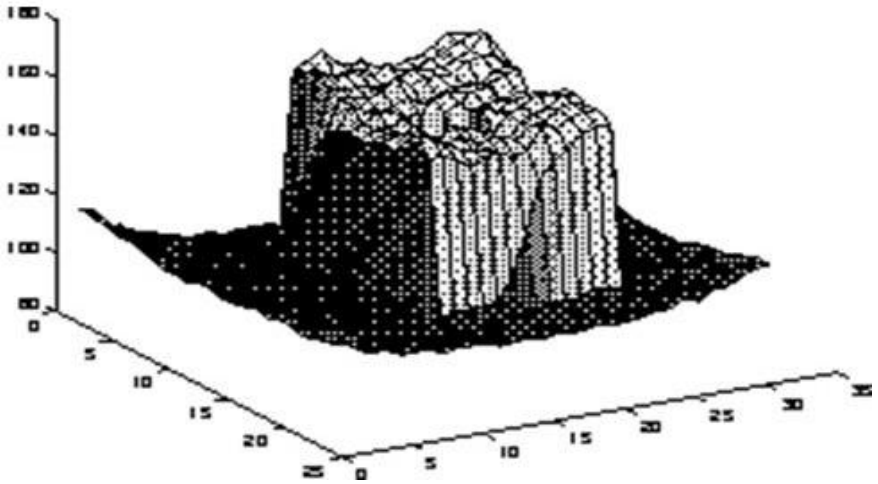


Sampling + Quantization

Image courtesy: wikipedia

Image = *f(x,y)*





Analog vs. Digital signal (2-D signal)

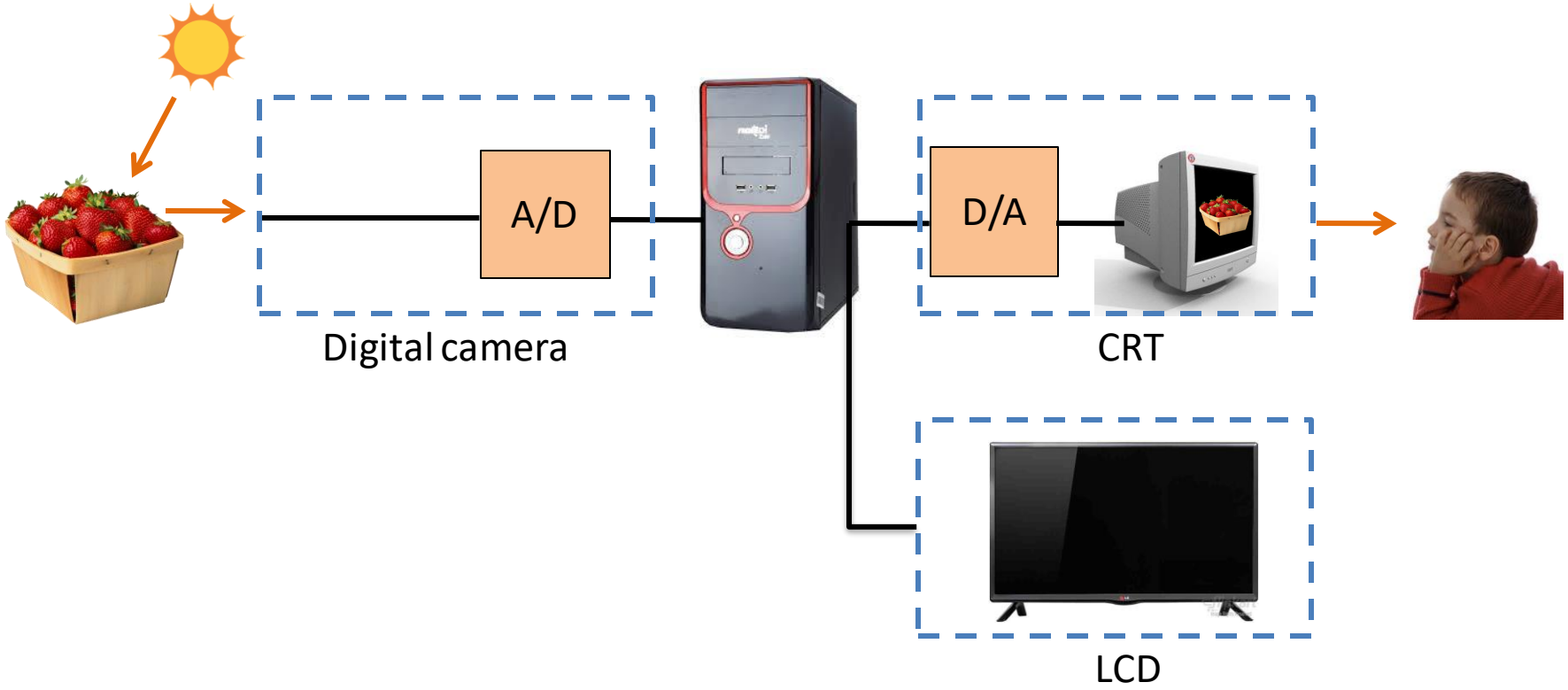


Image acquisition process

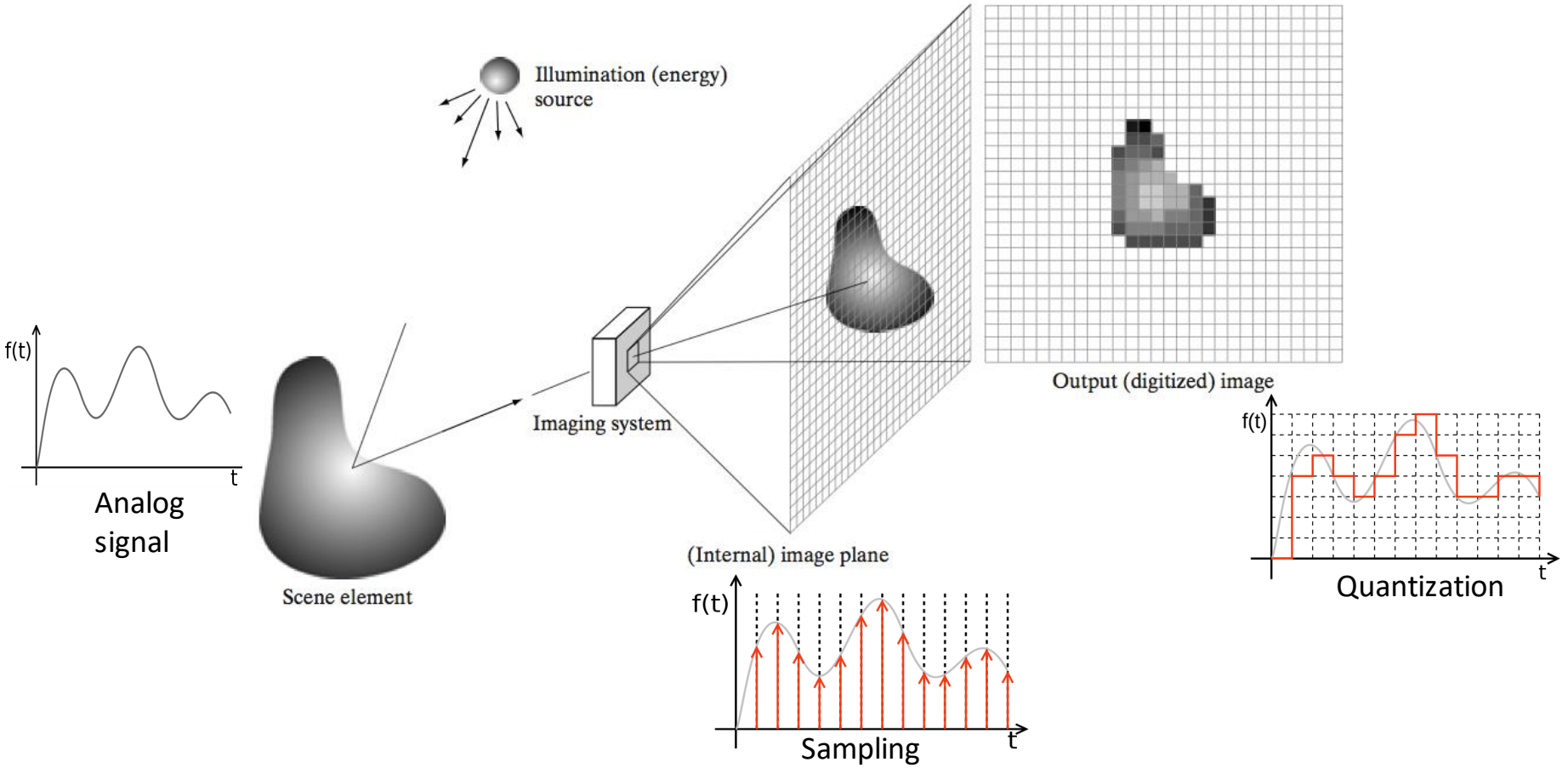
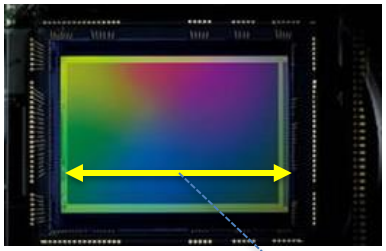


Image courtesy: Gonzalez and Woods

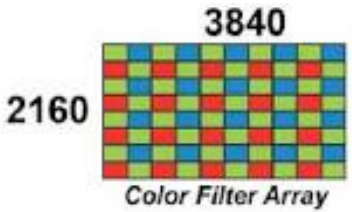
Cross-section of typical smartphone camera

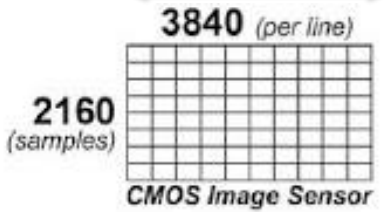
Physical Characteristics	
Active image area size	24.6 (H) x 13.8 (V) mm
Total number photosites	4206 (H) x 2340 (V)
Number photosites for active image	3840 (H) x 2160 (V)
Color filter array (with microlens)	RGB Bayer
Size of photosite (microns)	6.4 (H) x 6.4 µm
Pixel pitch	6.4 µm
Power supply	3.3v / 1.8v
Power consumption	950mW

Resolution (of the sensor)

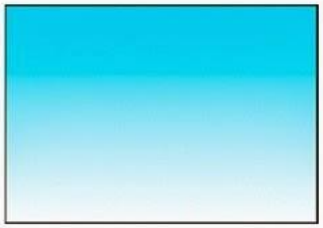


24.6 mm





Digital Camera Sensor Sizes



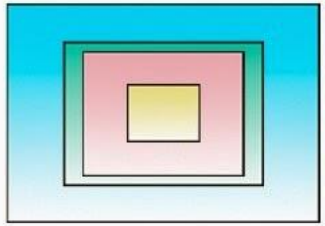
Full Frame Sensor

APS Size Sensor

Micro Four Thirds Sensor

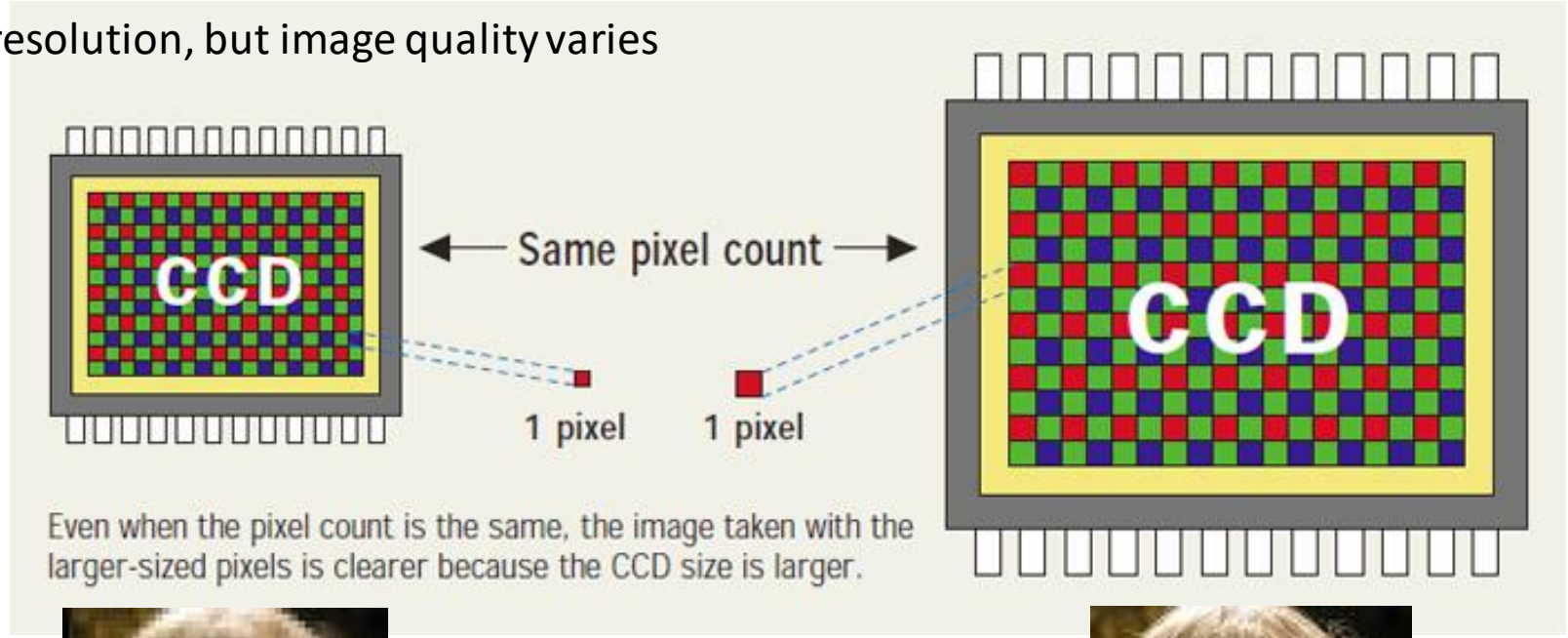
Point and Shoot Sensor

Sensor Size Comparison

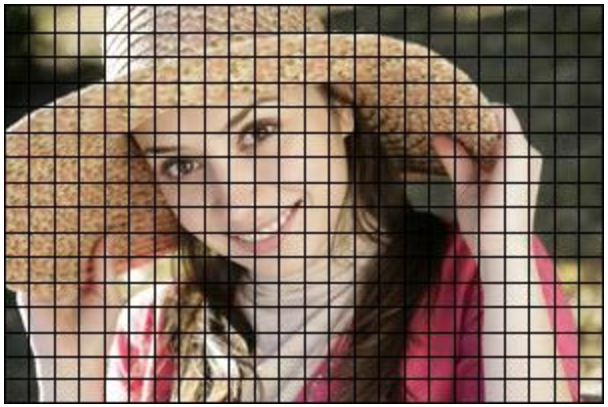



SONY
make.believe
α
Size matters. Larger sensor provides better quality images.
Sony 35mm Full frame
Exmor
Sony APS-C
Exmor
Micro Four Thirds
CX Format
Compact Camera
1/2.3 format
30 x
13 x
7.9 x
4.1 x
1 x
Approximate Size Ratio
PHOTOGRAPHY BAY

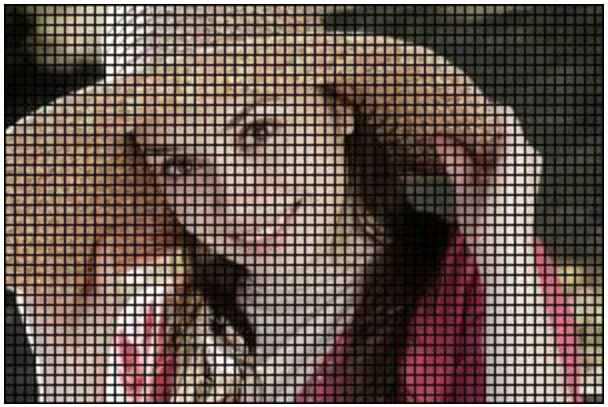
Same resolution, but image quality varies



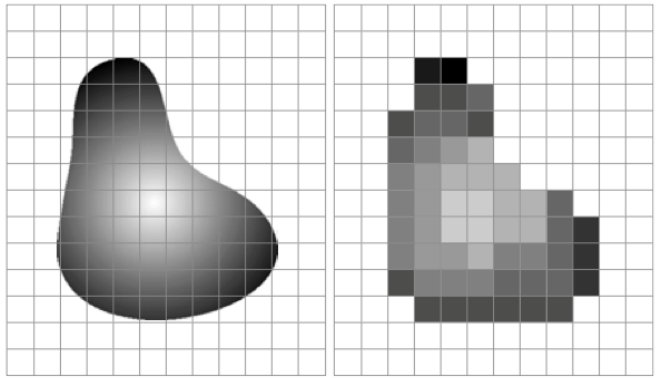
Same sensor size, but # of sensor pixels/mm varies



Small number of CCD pixels

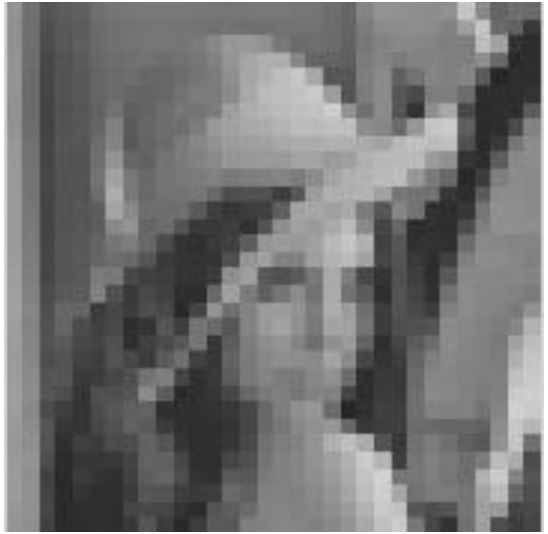


Large number of CCD pixels

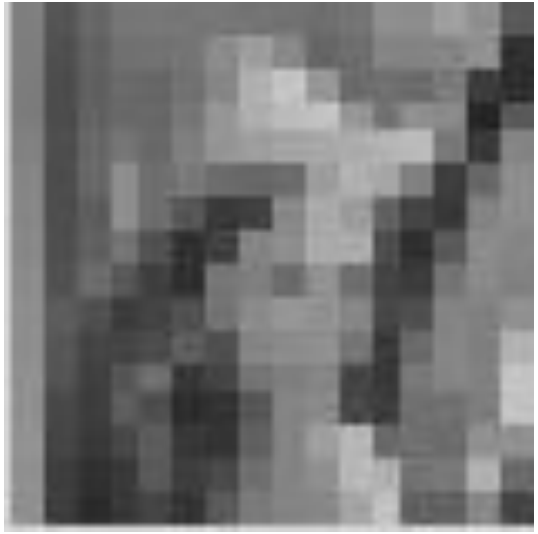


Sampling – Spatial Quantization

256 × 256



32 × 32



16 × 16

Image acquisition process

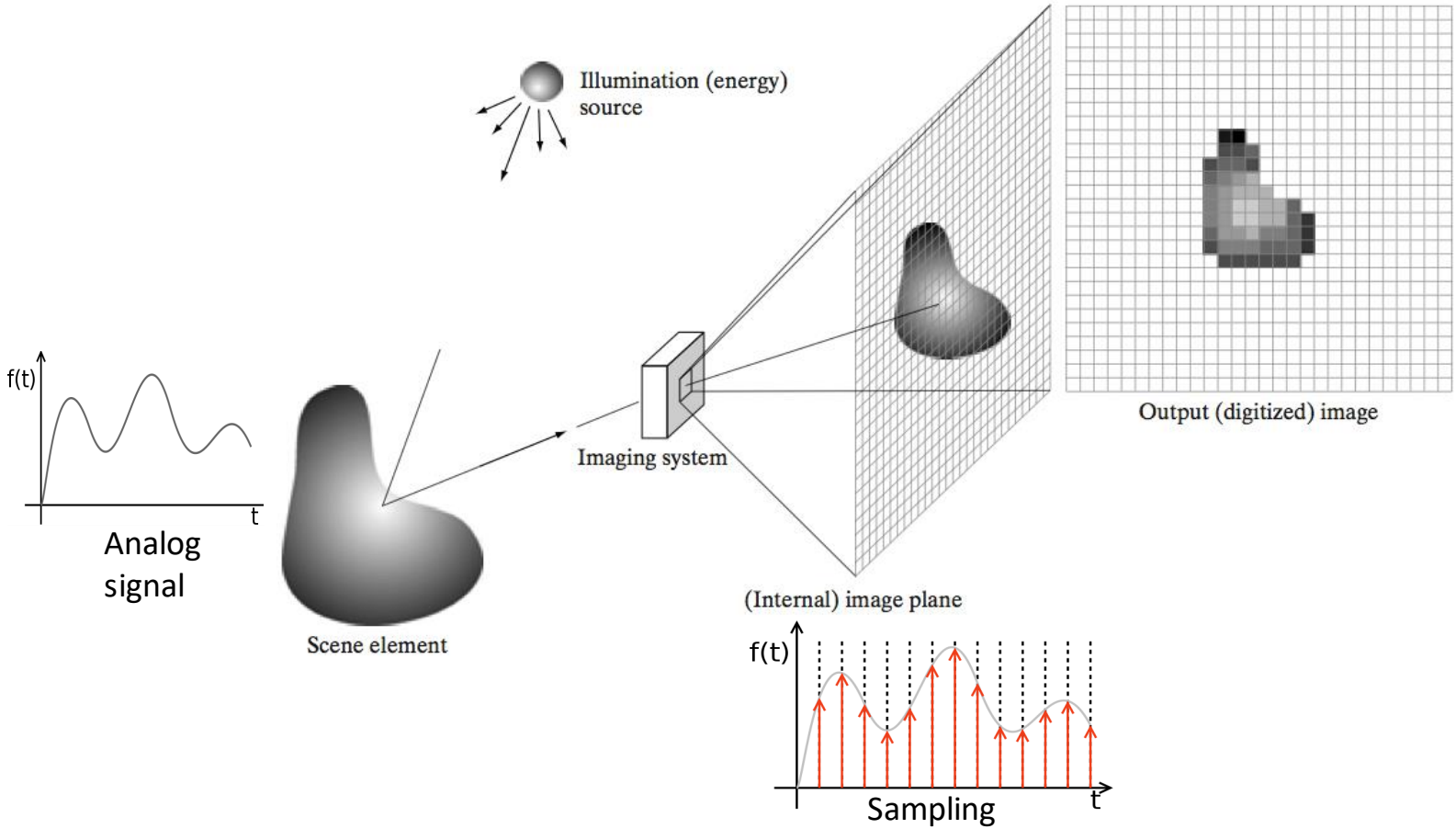


Image courtesy: Gonzalez and Woods

Image acquisition process

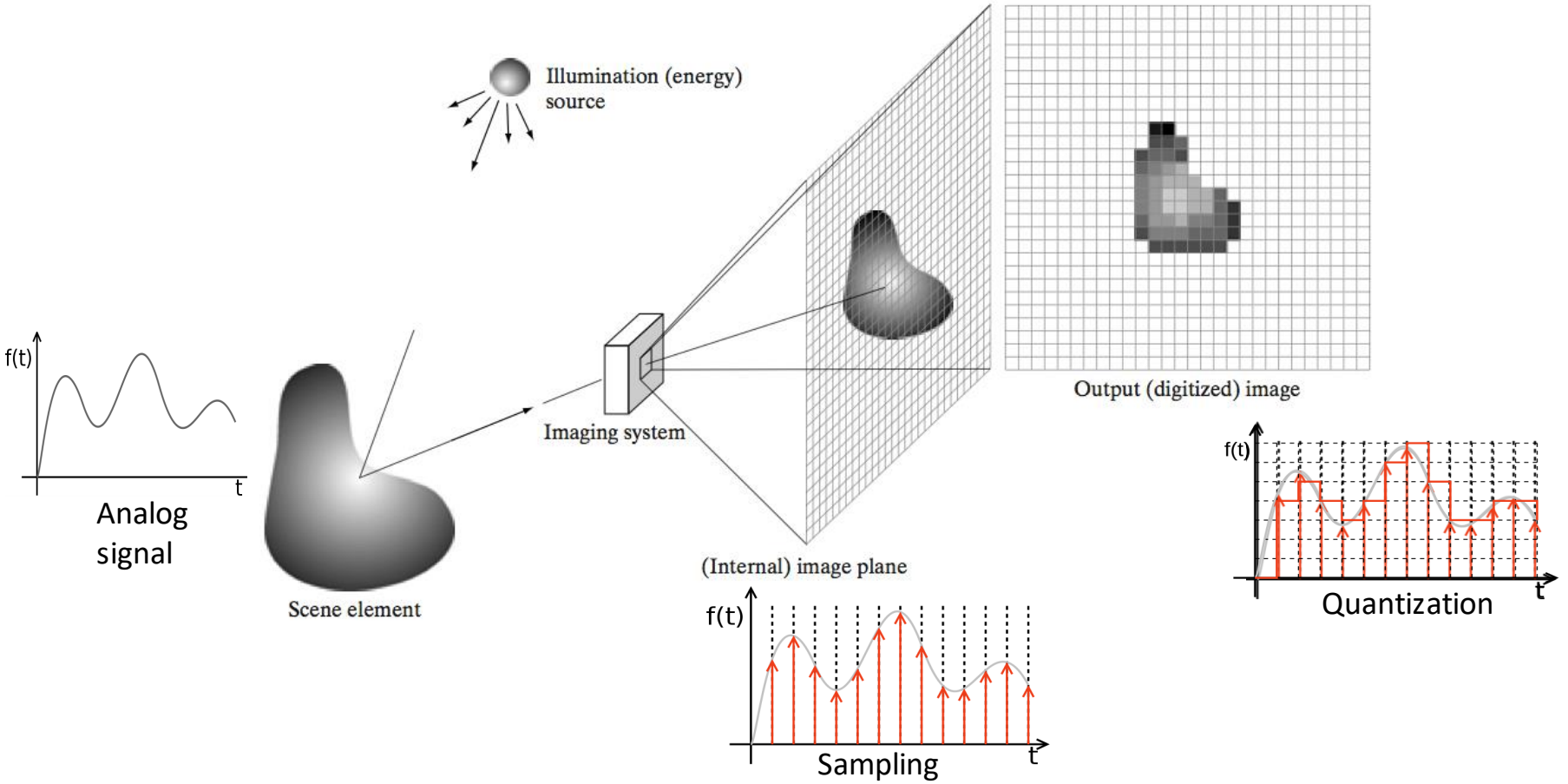


Image courtesy: Gonzalez and Woods

Intensity Quantization

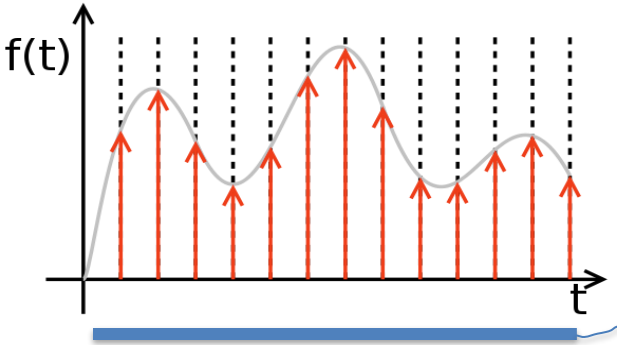
8 bits per pixel

4 bits per pixel

2 bits per pixel

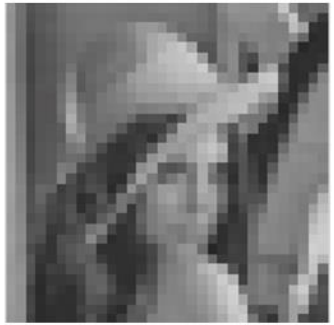
1 bit per pixel

Summary

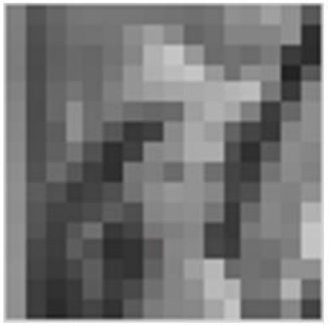


Sampling

256 × 256

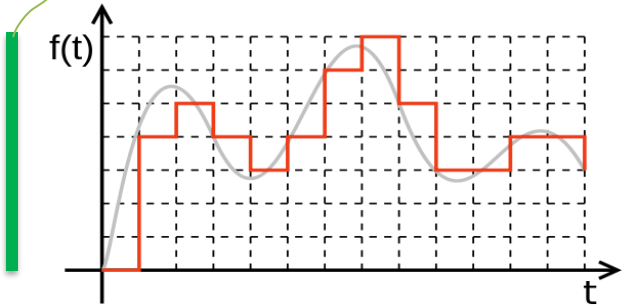


32 × 32



16 × 16

Quantization



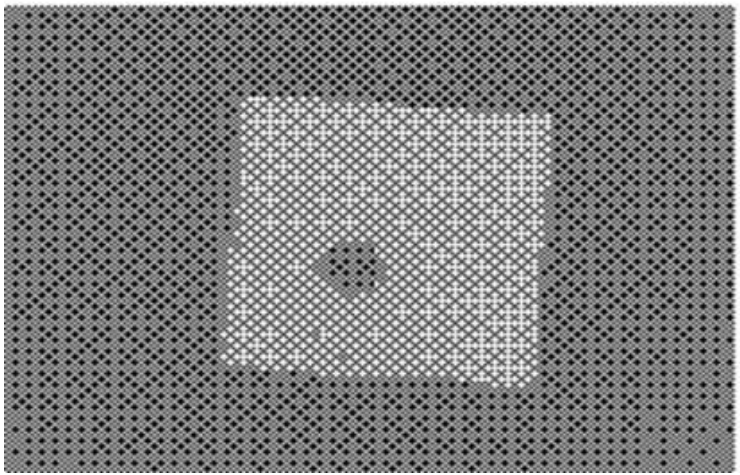
8 bits per pixel

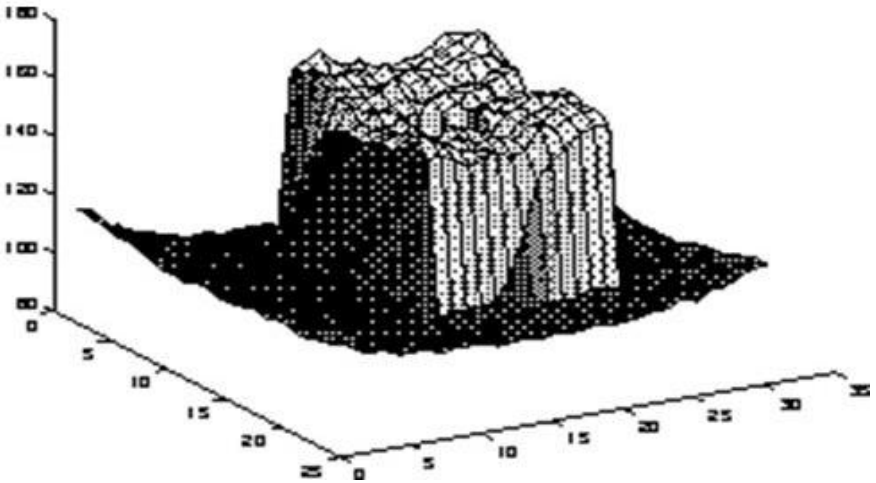
4 bits per pixel

2 bits per pixel

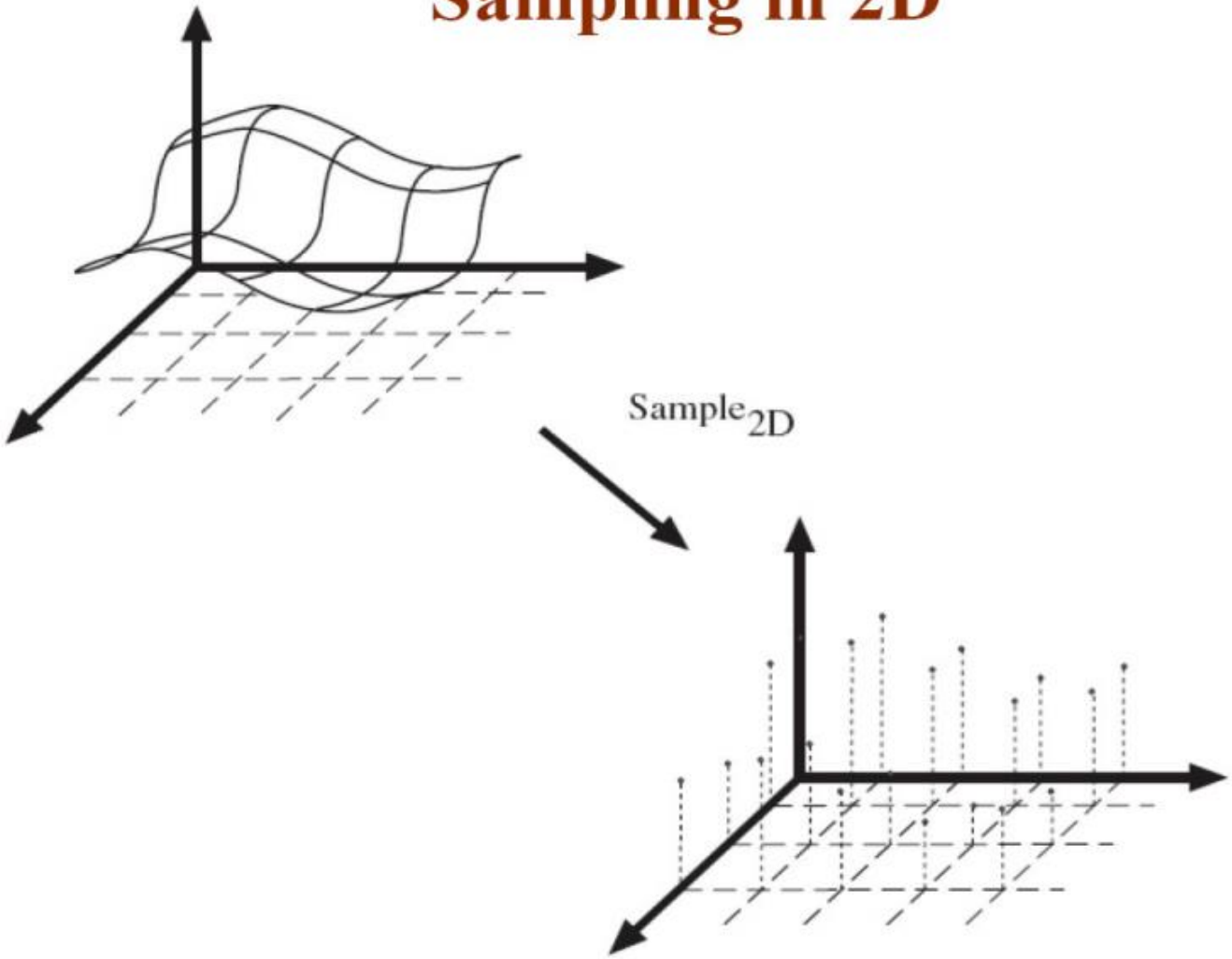
1 bit per pixel

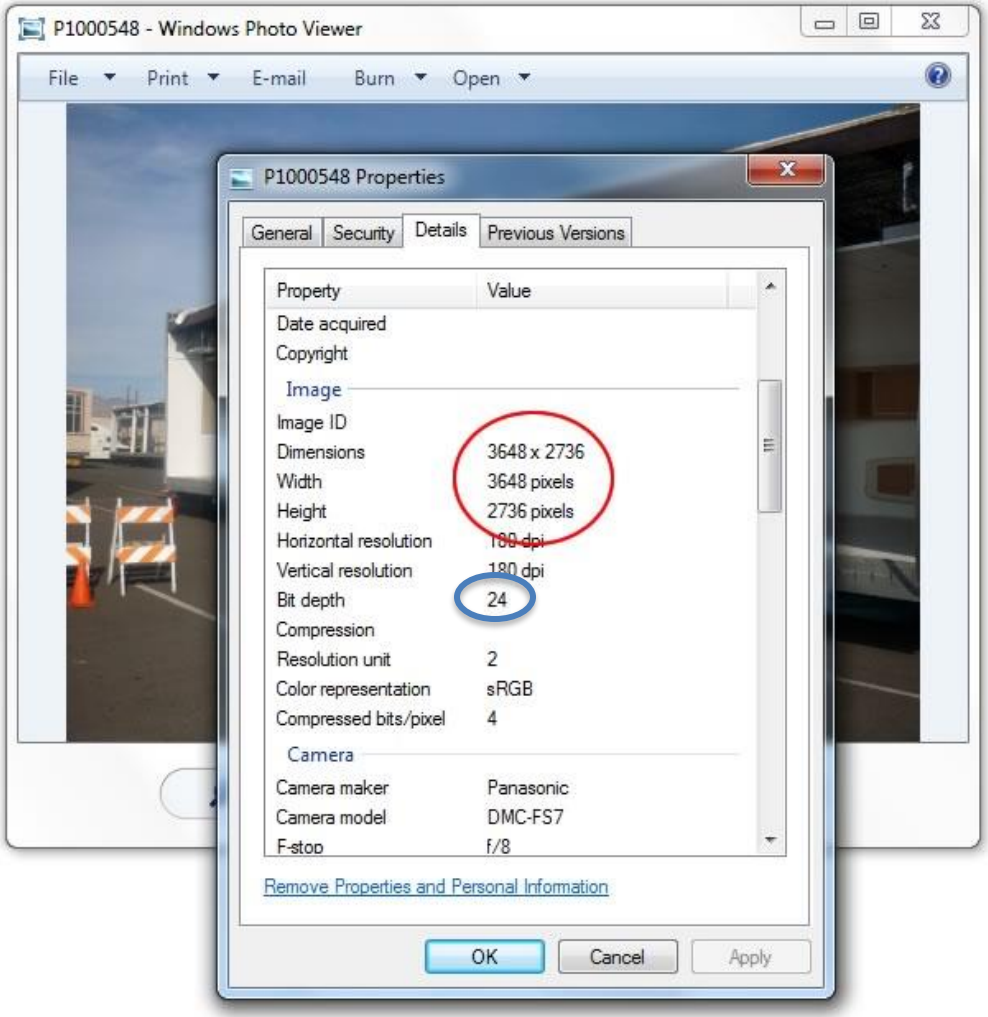
Image as a 3D surface





Sampling in 2D




P1000548 - Windows Photo Viewer
File
Print
E-mail
Burn
Open
P1000548 Properties
General
Security
Details
Previous Versions
Property
Value
Date acquired
Copyright
Image
Image ID
Dimensions
3648 x 2736
Width
3648 pixels
Height
2736 pixels
Horizontal resolution
180 dpi
Vertical resolution
180 dpi
Bit depth
24
Compression
Resolution unit
2
Color representation
sRGB
Compressed bits/pixel
4
Camera
Camera maker
Panasonic
Camera model
DMC-FS7
F-stop
f/8
Remove Properties and Personal Information
OK
Cancel
Apply

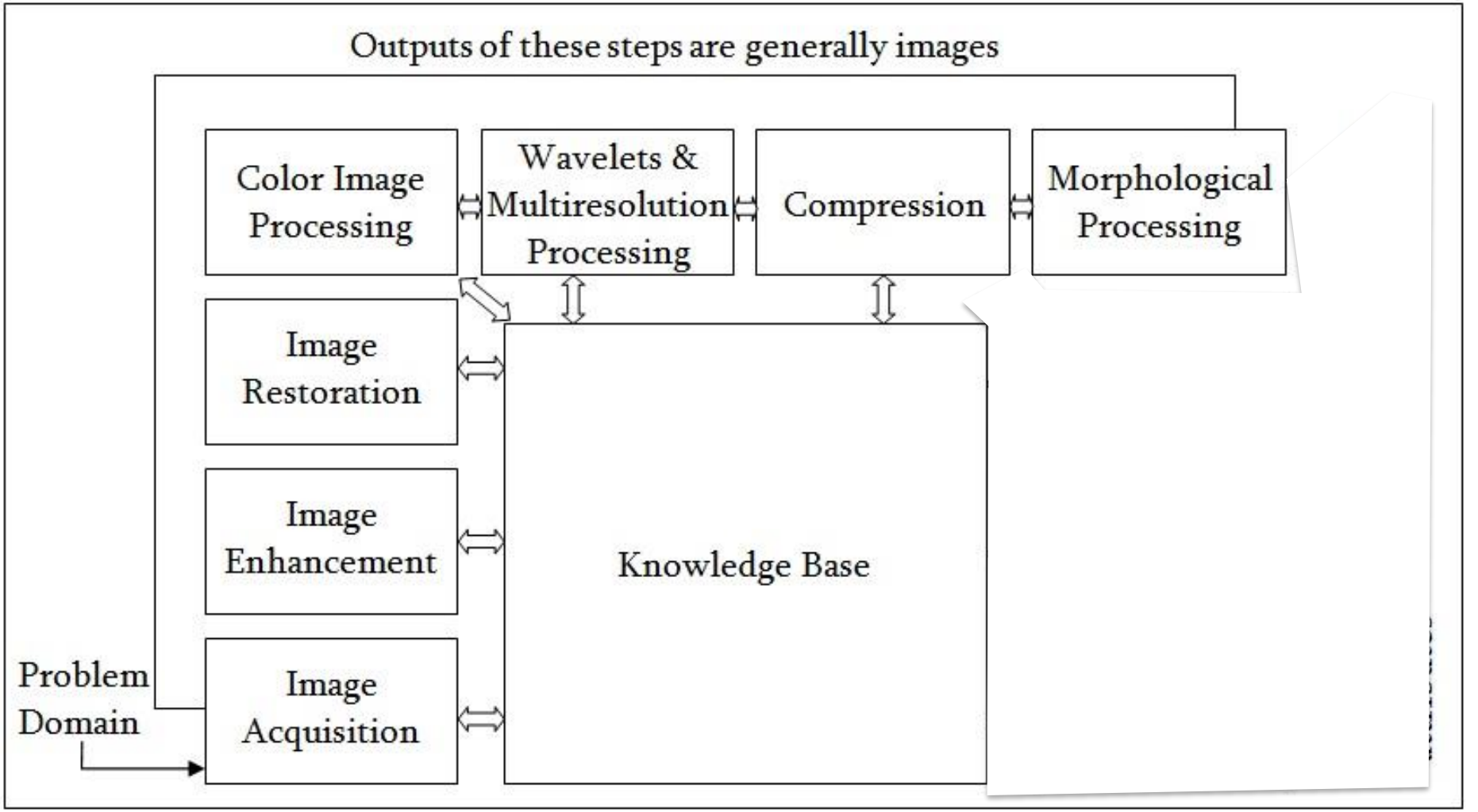
Additional Notes on Sampling and Quantization

- Temporal sampling → exposure time

Quantization

- Hardware (# of voltage levels, # of bits)
- Software (raw → JPEG)

- Digital Image Acquisition
- Image Sampling and Quantization
- **Fundamental Steps in Image Processing**


Outputs of these steps are generally images
Color Image Processing
Wavelets & Multiresolution Processing
Compression
Morphological Processing
Image Restoration
Image Enhancement
Image Acquisition
Knowledge Base
Problem Domain

Outputs of these steps are generally images

Color Image Processing

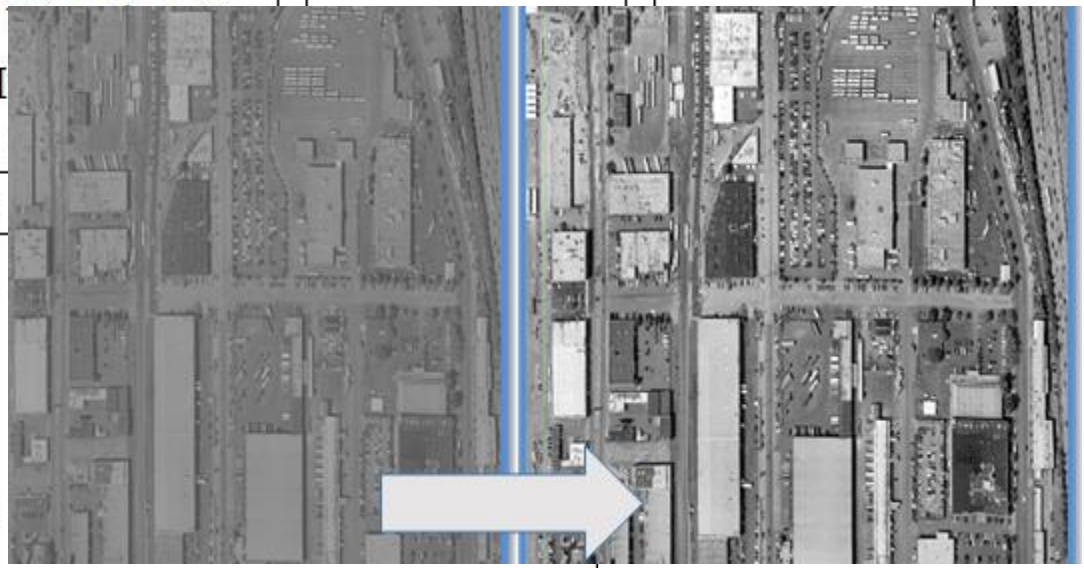
M

Image Restoration

Image Enhancement

Image Acquisition

Problem Domain



Outputs of these steps are generally images

Color Image Processing

Wavelets & Multiresolution Processing

Compression

Morphological Processing

Image Restoration

Image Enhancement

Problem Domain

Image Acquisition

Outputs of these steps are generally images

Color Image Processing

Wavelets & Multiresolution Processing

Compression

Morphological Processing

Image Restoration

Image Enhancement

Image Acquisition

Problem Domain

Uncorrected Image

With .Look Applied

Outputs of these steps are generally images

Color Image Processing

Wavelets & Multiresolution Processing

Compression

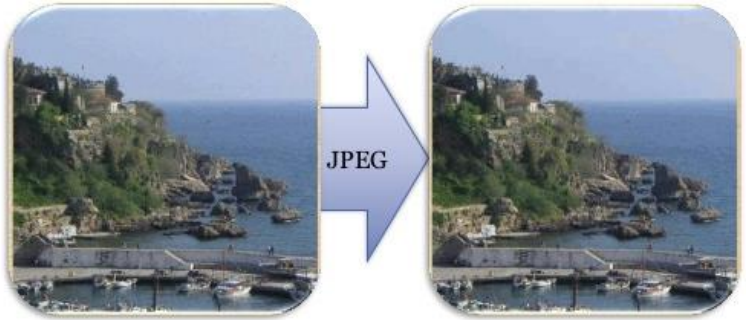
Morphological Processing

Image Restoration

Image Enhancement

Image Acquisition

Problem Domain



"Without Compression a CD store only 200 Pictures or 8 Seconds Movie"

Outputs of these steps are generally images

Color Image Processing

Wavelets & Multiresolution Processing

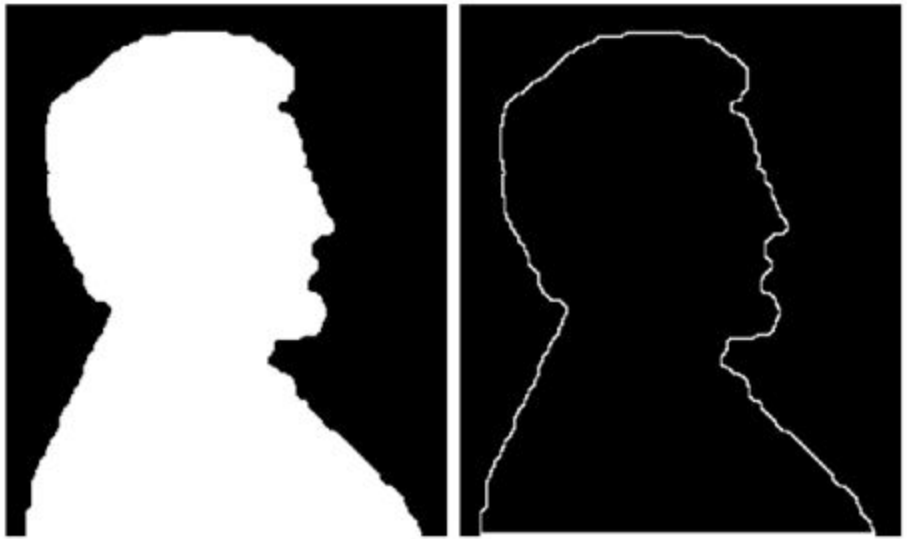
Compression

Morphological Processing

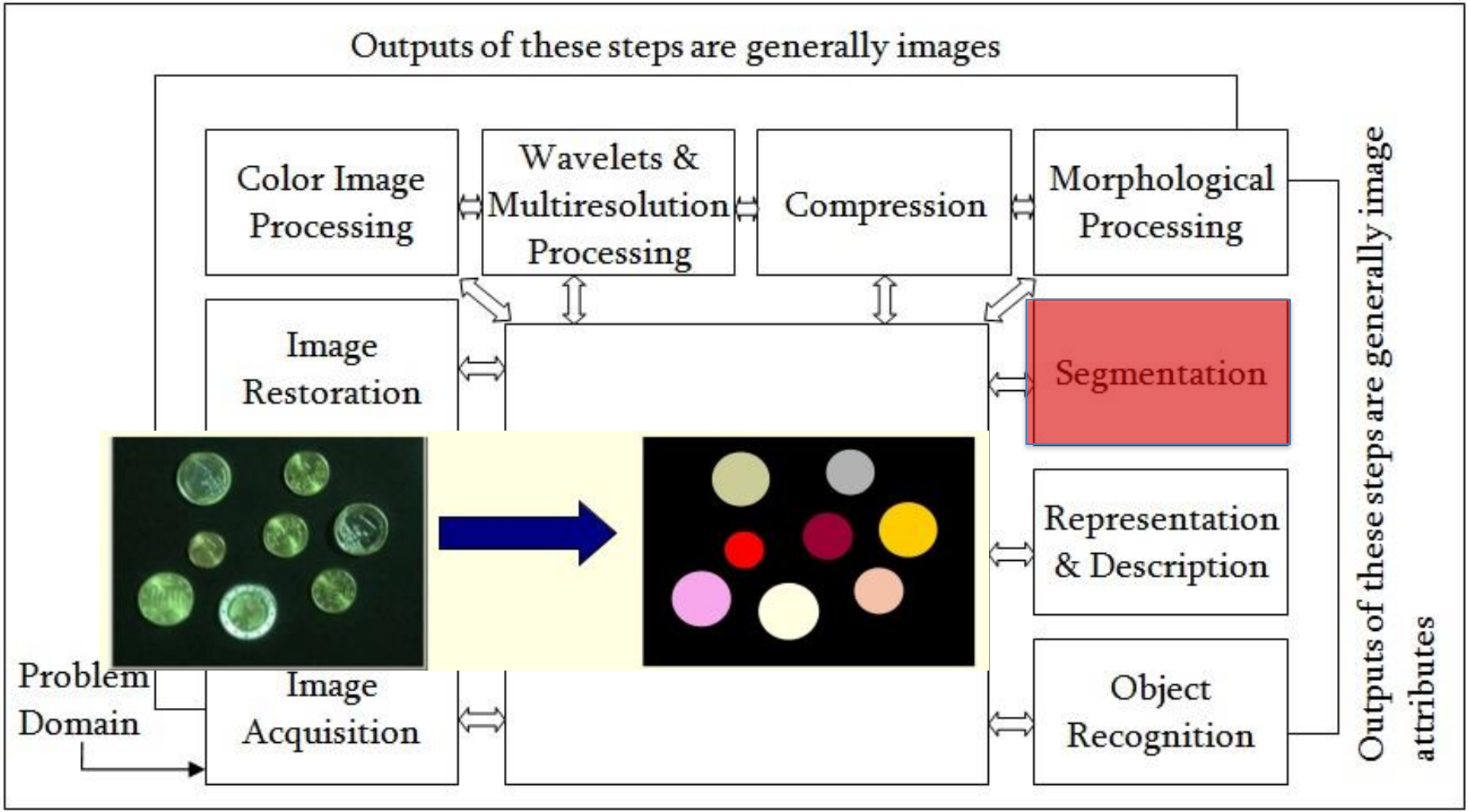
Image Restoratio

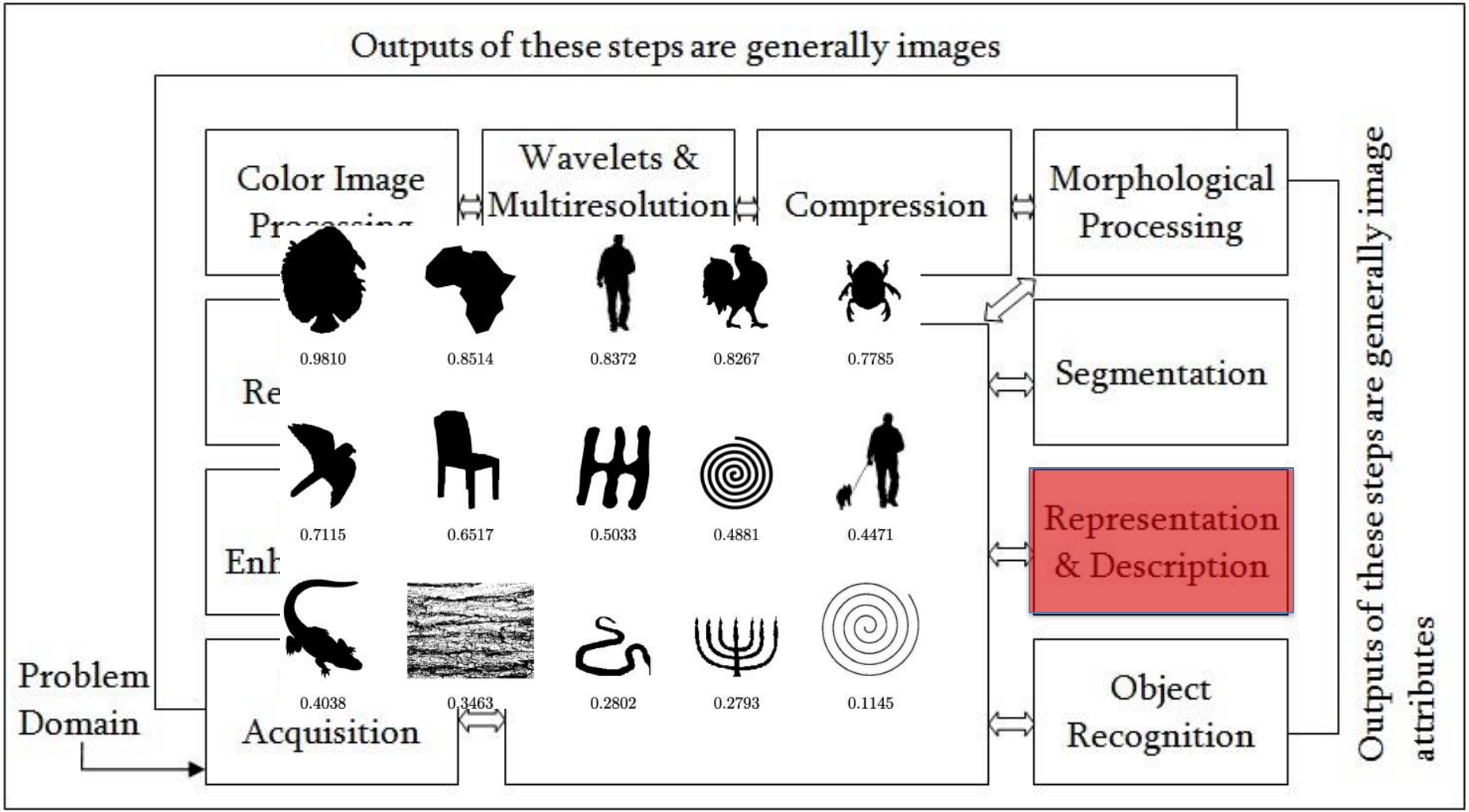
Image Enhancem

Image Acquisitio

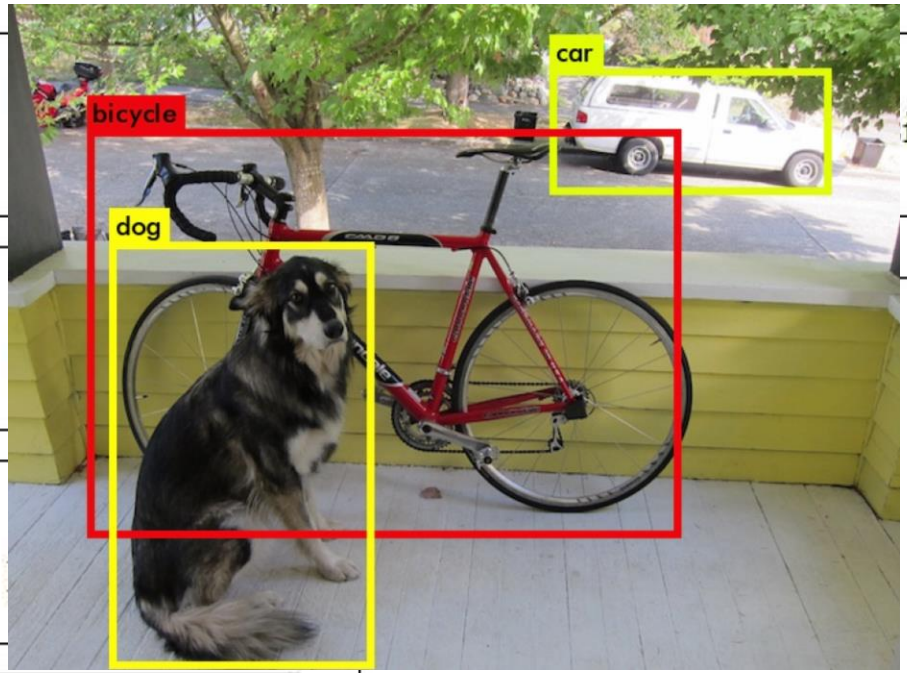


Problem Domain


Outputs of these steps are generally images
Color Image Processing
Wavelets & Multiresolution Processing
Compression
Morphological Processing
Image Restoration
Segmentation
Representation & Description
Problem Domain
Image Acquisition
Object Recognition
Outputs of these steps are generally image attributes


Outputs of these steps are generally images
Color Image Processing
Wavelets & Multiresolution
Compression
Morphological Processing
Segmentation
Representation & Description
Object Recognition
Acquisition
Problem Domain
Outputs of these steps are generally image attributes
0.9810
0.8514
0.8372
0.8267
0.7785
0.7115
0.6517
0.5033
0.4881
0.4471
0.4038
0.3463
0.2802
0.2793
0.1145

Outputs of these steps are generally images



Problem Domain

Image Acquisition

ion

Morphological Processing

Segmentation

Representation & Description

Object Recognition

Outputs of these steps are generally image attributes

What we saw today

Human Eye

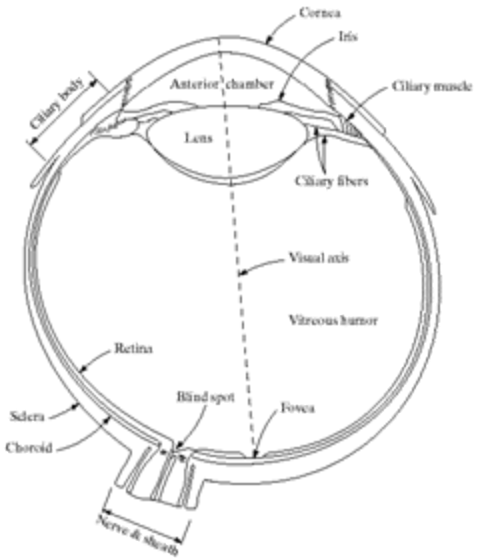
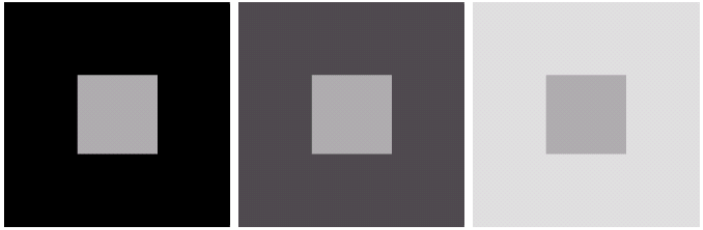


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

Brightness adaptation & Psychovisual effects



a b c

FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

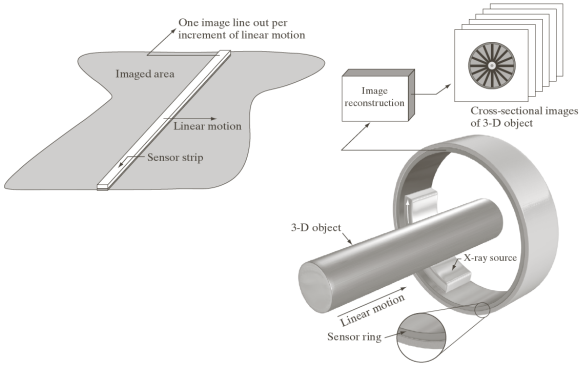
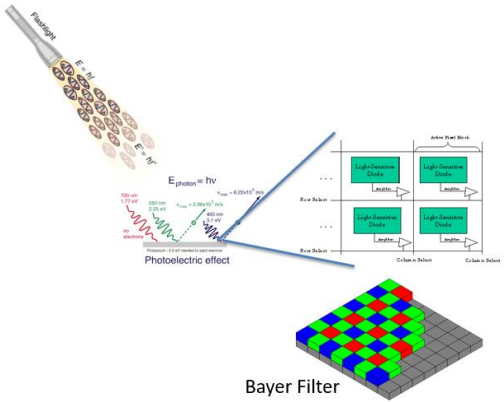
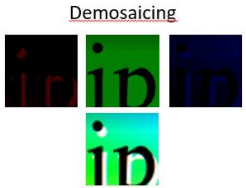


Image Sensing and Acquisition

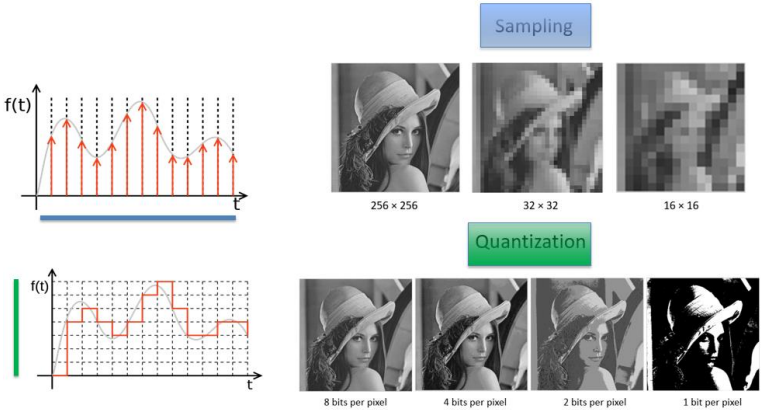
What we saw today

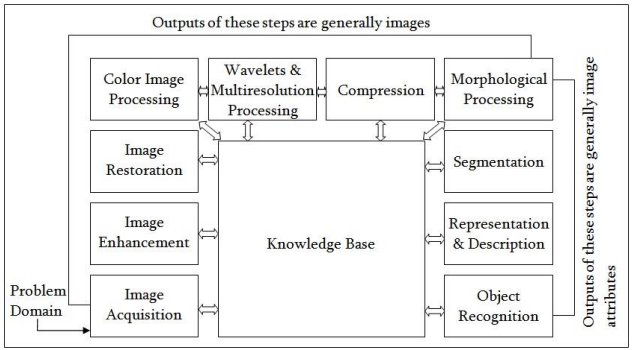
Digital Image Acquisition





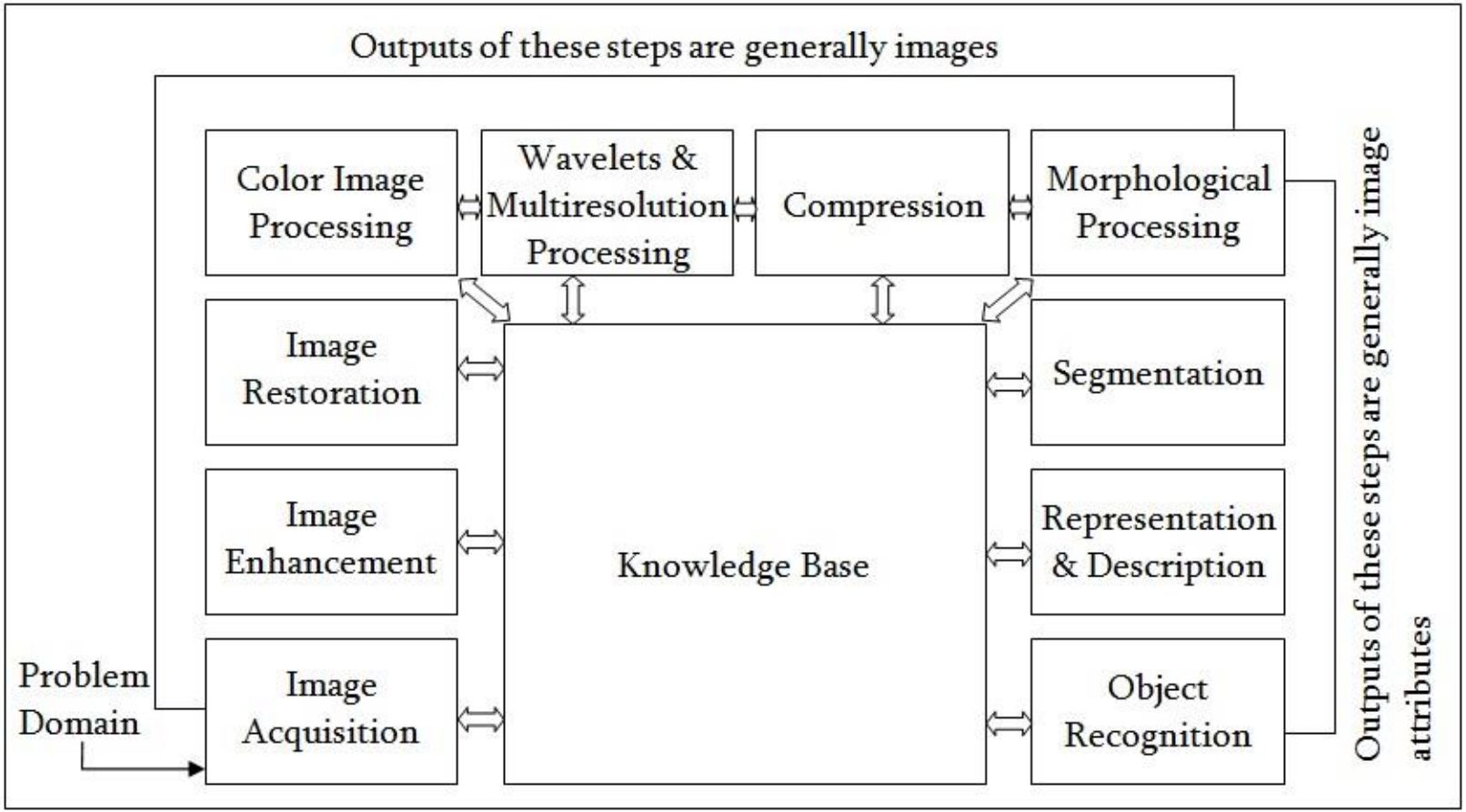
Sampling and Quantization





Fundamental Steps in Image Processing

What we saw today



References

- Gonzalez and Woods (2.1,2.3-2.4)
  - Problems : 2.1 – 2.10